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Department of Energy
Oak Ridge Operations
Paducah Site Office
P.O. Box 1410
Paducah, KY 42001

February 12, 2003

cy: Document Center
Vanstickle
Wheeler
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Massey
Jolly
Davis

Mr. Gordon L. Dover
Manager of Paducah Programs
Bechtel Jacobs Company LLC
761 Veterans Avenue
Kevil, Kentucky 42053

Dear Mr. Dover:

REPLY TO NORTH-SOUTH DIVERSION DITCH AUTHORIZED LIMITS REQUEST FOR PROPOSED SOLID WASTE DISPOSAL AT THE C-746-U LANDFILL AT THE PADUCAH GASEOUS DIFFUSION PLANT

The authorized limits developed by the Paducah Site Office have been approved by the Paducah Field Office Manager in Oak Ridge. The authorized limits were developed for the disposal of soils and debris containing residual amounts of radioactive materials over a period of seven years. The amounts and type of residual radioactive materials allowed are discussed in detail in the enclosed document. The enclosed Authorized Limits Request meets all requirements of DOE-STD-5506-99, Guide to Good Practice for Establishing Authorized Limits for the Release of Waste Containing Residual Radioactivity, and DOE-Order-5400.5, Radiation Protection of the Public and the Environment.

The information provided on the North/South Diversion Ditch was used for establishing initial authorized limits for the C-746-U Landfill as well as authorized limits for successive materials for the next seven years. Each time a waste stream is produced from a specific project, the authorization limits for the landfill will have to be re-evaluated by the Site Office Health Physicist.

If you have any questions or require additional information, please call Mitch Hicks at (270) 441-6820.

Sincerely,

W. Don Seaborg, Site Manager
Paducah Site Office

Enclosure

Document no longer contains OUO information.

cc w/enclosure:
K. Ausbrooks, BJC/Kevil
S. J. Davis, BJC/Kevil

cc w/o enclosure:
W. E. Murphie, EM-1

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Department of Energy review required before public release
Name/Org: M. R. Brennan Sem-Tech Sys Date: 3 June 03
Guidance (if applicable) N/A

I-04816-0045

AUTHORIZED LIMITS REQUEST
FOR SOLID WASTE DISPOSAL AT LANDFILL C-746-U
AT THE PADUCAH GASEOUS DIFFUSION PLANT

November 2002
Revised January 2003

U.S. Department of Energy
Oak Ridge Operations Office
Oak Ridge, Tennessee

Approved by RCS / Date: 2/6/03

CONTENTS

TABLES

FIGURES

AUTHORIZED LIMITS REQUEST FOR SOLID WASTE DISPOSAL AT LANDFILL C-746-U AT THE PADUCAH GASEOUS DIFFUSION PLANT

EXECUTIVE SUMMARY

This document contains data and analyses to support the approval of authorized limits for the release of soil and debris wastes generated at the Paducah Gaseous Diffusion Plant (PGDP) at Paducah, Kentucky, for disposal at the C-746-U on-site landfill. The C-746-U landfill is owned by the U.S. Department of Energy (DOE) and operated by the Waste Operations organization of the Bechtel Jacobs Company LLC. Operation of the facility is regulated by DOE, the Commonwealth of Kentucky, and the U.S. Environmental Protection Agency (EPA) under the provisions of the Atomic Energy Act (AEA), Resource Conservation and Recovery Act (RCRA), Toxic Substances Control Act (TSCA), Department of Transportation (DOT) regulations, and the Kentucky Solid Waste Landfill Regulations (401 KAR 48).

DOE requirements for release of non-real property, including solid waste, containing low levels of residual radioactive materials are specified in DOE Order 5400.5 and associated guidance contained in DOE Standard 5506-99. One of the specific requirements for disposal of solid waste at a DOE-owned, on-site landfill such as C-746-U is an evaluation to ensure that radiation doses to the public would be As Low As Reasonably Achievable (ALARA). The goal for the doses would be a few milli-rem/year (mrem/year), not to exceed 25 milli-rem/year. Other specific requirements for disposal is an evaluation of compliance with groundwater protection, and reasonable assurance that the proposed disposal is not likely to result in a future need for remediation of the landfill.

Authorized limits proposed in this document would apply to the disposal of soil and debris wastes generated from construction, maintenance, environmental restoration, and decontamination and decommissioning activities at the PGDP at the C-746-U landfill. Initial application of the authorized limits will be towards soil and debris generated from the remedial action of the North-South Diversion Ditch (NSDD). This waste stream will contain low levels of residual radioactive materials, due to the presence of naturally occurring radionuclides and incidental contamination from site operations. The volume of waste to be disposed under the proposed authorized limits is approximately 11,795 m^3 (11,795 cubic meters) for material from the NSDD with an estimated 5,000 m^3 per year for the following years from other remediation efforts. This would encompass a period of approximately 7 years. Annual evaluations would be conducted by a Health Physicist to confirm that the characteristics of waste disposed at the facility during each year of operation are consistent with the assumptions used to derive these authorized limits.

The potential radiation dose from management of the proposed PGDP soil and debris waste stream at the C-746-U landfill is estimated at approximately 2 mrem/year to an exposed worker at the C-746-U facility. And 0.008 mrem/year to the maximally exposed member of the

off-site public during operation of the landfill. Detrimental impacts to groundwater quality would not be expected to result from the management of this waste stream at the C-746-U landfill, nor would any requirement for future remediation of the landfill due to the disposal of this waste be expected. Disposal of this waste stream at the C-746-U landfill also would result in cost savings of approximately $1-3 million per year, relative to off-site disposal alternatives. Savings on the NSDD project disposal costs alone would be over $2 million.

The results of this analysis indicate that release of PGDP soil and debris wastes containing low levels of residual radioactive material for disposal at the C-746-U landfill would be fully protective of human health and the environment, and would meet all requirements of DOE Order 5400.5 and associated guidance. This waste management alternative would satisfy all applicable requirements and would be consistent with DOE's policy to reduce radiation exposures As Low As Reasonably Achievable (ALARA). On this basis, DOE has determined that the residual radioactive materials in the proposed PGDP soil and debris waste stream do not require control under the AEA and can be safely managed at the C-746-U landfill.

1. INTRODUCTION

1.1 Purpose

This document contains data and analyses to support the approval of authorized limits for the release of specified solid wastes generated at the Paducah Gaseous Diffusion Plant (PGDP) at Paducah, Kentucky, for disposal at the C-746-U on-site landfill. The C-746-U landfill is owned by the U.S. Department of Energy (DOE) and operated by the Waste Operations organization of the Bechtel Jacobs Company LLC. Operation of the facility is regulated by DOE, the Commonwealth of Kentucky, and the U.S. Environmental Protection Agency (EPA) under the provisions of the Atomic Energy Act (AEA), Resource Conservation and Recovery Act (RCRA), Toxic Substances Control Act (TSCA), Department of Transportation (DOT), and the Kentucky Solid Waste Landfill Regulations. The wastes proposed for disposal at the C-746-U landfill under this request include soils and debris that may contain low levels of residual radioactive materials, due to the presence of naturally occurring radionuclides and/or incidental contamination during site operations, that do not require control under the AEA. The initial waste stream to be considered for disposal in C-746-U landfill will come from the North-South Diversion Ditch (NSDD).

1.2 DOE Requirements for Release of Non-Real Property

U.S. Department of Energy (DOE) requirements for release of real (e.g., land and structures) and non-real property (e.g., waste) are specified in Chapters II and IV of DOE Order 5400.5 (DOE 1993). Specific guidance on the release of non-real property, including wastes for disposal and items for reuse or recycle, is provided in a memorandum issued by the DOE Office of Environmental Policy and Assistance (EH-41) on November 17, 1995 (Attachment 1, DOE Standard 5506-99). This guidance includes specific requirements for disposal of DOE wastes at DOE-operated on-site landfills and non-DOE off-site landfills, which are not authorized for disposal of radioactive waste.

In the case of DOE-owned on-site landfills, such as the C-746-U facility at PGDP, DOE has the responsibility and authority to establish limits for protection of the public and the environment, either in the form of radionuclide release criteria or waste acceptance criteria for disposal of materials in the landfill. Disposal of such material must meet the requirements of DOE Order 5400.5 and applicable portions of DOE Order 435.1. Authorized limits for material sent to a DOE on-site landfill, which is not an authorized low-level waste disposal facility must meet the following requirements:

1. Authorized limits must be selected and approved by DOE on the basis of an assessment under the ALARA process to optimize the balance between risks and benefits. The assessment will include costs, and collective doses to ensure that individual doses to the public are less than 25 mrem/year with a goal of a few mrem/year or less.

2. Authorized limits must be evaluated to ensure that groundwater will be protected in a manner consistent with the objectives of the site's Groundwater Protection Program objectives (DOE Order 5400.1) and applicable Federal or State requirements.

3. Authorized limits must be evaluated to verify that the release of the landfill property would not be expected to require remediation under DOE Order 5400.5 requirements for release of property containing residual radioactive material. Consideration will be given to experience gained from past or ongoing CERCLA or RCRA cleanup actions [e.g., any radionuclide concentration limits established in CERCLA or RCRA records of decision at the site].

Additional guidance for coordination with facility operators and regulators was issued in a memorandum dated January 7, 1997 (Attachment 2, DOE Standard 5506-99) by the DOE Office of Waste Management (EM-37). The EM-37 guidance reconfirmed that the EH-41 guidance may be used for the release of hazardous waste to permitted Treatment, Storage, and Disposal (TSD) facilities.

1.3 Site Location and Background

The Paducah Gaseous Diffusion Plant is an operating DOE facility located in northwestern Kentucky in McCracken County, approximately 10 miles west of Paducah, Kentucky, and 4 miles south of the Ohio River. The facility produces enriched uranium for use in commercial nuclear power reactors. The enrichment process involves conversion of uranium hexaflouride (UF_6) to compressed gas, which is processed through a long series of diffusion stages. Enrichment operations at PGDP increase the amount of the radioisotope ^{235}U in the process material from the natural abundance of about 0.7 percent to approximately 3 percent (by mass).

The PGDP was constructed from 1951 to 1954, and began uranium production operations in 1952. The Union Carbide Corporation operated the facility until 1984. Martin Marietta Energy Systems, Inc. (later Lockheed Martin Energy Systems, Inc.) then operated the facility from 1984 to 1993 under contract to DOE. In July 1993, the United States Enrichment Corporation (USEC), which was created by the U.S. Congress through the Energy Policy Act of 1992, leased uranium enrichment production facilities from DOE and became responsible for production of enriched uranium. USEC was privatized as an investor-owned corporation through an initial public offering in 1998 to be more competitive in the global market for enriched uranium. USEC contracted Lockheed Martin Utility Services, Inc., to operate the PGDP prior to May 1999, when USEC took over direct operation of all uranium enrichment operations at the plant.

DOE maintains ownership of the PGDP site, and is responsible for environmental restoration and DOE legacy waste management activities. In 1998, DOE contracted Bechtel Jacobs Company LLC as its management and integration (M&I) contractor responsible for directing its environmental management and enrichment facilities program at PGDP. Regulatory oversight of the USEC uranium enrichment operations was transferred from DOE to the Nuclear Regulatory Commission (NRC) in 1997, based on a certificate of compliance under 10 CFR 76 issued in November 1996.

The C-746-U landfill was constructed in 1995 for disposal of solid wastes not regulated as hazardous materials under RCRA or TSCA regulations. The landfill is located north of the PGDP main plant area and is permitted by the Commonwealth of Kentucky in accordance with

the requirements of Kentucky solid waste regulations (401 KAR 48, *Standards for Solid Waste Facilities*) and Subtitle D of RCRA. Wastes that may be acceptable for disposal at the C-746-U facility include soils, wood, concrete, roofing and construction debris, and other non-hazardous sanitary and industrial wastes [e.g., paper, fly ash, medical waste, asbestos, cardboard, tires, animal carcasses, detectable PCB (<50 ppm) waste, personal protective equipment, plastic, alkaline batteries, metals]. The facility is not approved for disposal of RCRA or TSCA regulated hazardous wastes nor low-level radioactive waste. However, some wastes that may be considered for disposal at this facility may contain residual levels of radioactive material from the presence of naturally-occurring radionuclides or incidental contamination from site operations. This document has been developed to support the approval of authorized limits for such materials.

1.4 Benefit of Disposal at the C-746-U Landfill

Disposal of PGDP soil and debris wastes containing low levels of residual radioactive materials at the C-746-U landfill would provide significant cost savings, relative to other currently available disposal alternatives. Much of the soil and debris waste generated at PGDP may contain low levels of radioactive materials due to the presence of naturally occurring radionuclides, such as uranium or thorium, or due to incidental contamination from site operations. Off-site disposal of these materials as low-level radioactive waste would incur significantly greater costs, without providing commensurate reduction in risks to human health or the environment or other benefits. The results of this analysis indicate that the disposal of these materials at the C-746-U landfill would be protective of human health and the environment, while providing significant cost savings (approximately $ 1,000,000 to $3,000,000 per year) and immediate disposal capacity for this waste.

2. WASTE STREAM CHARACTERIZATION

Large volumes of soil and debris are generated from construction, maintenance, environmental restoration, and decontamination and decommissioning (D&D) activities at the PGDP. The C-746-U landfill may provide a cost-effective and protective alternative for disposal of such wastes. Debris may include construction or demolition rubble, as well as ancillary materials that may be associated with a remediation project and that meet the waste acceptance criteria (WAC) for the facility (e.g., asbestos wastes, personal protective equipment and clothing, paper, plastic, roofing materials). Waste acceptance criteria for the C-746-U landfill are specified in Section 7.4 of the document *Waste Acceptance Criteria for the Department of Energy Treatment, Storage, and Disposal Units at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (BJC 1999).

Soil and debris wastes at PGDP may contain low levels of residual radioactive materials, either due to the presence of naturally occurring radionuclides, such as uranium and thorium, in these materials or due to incidental contamination from site operations. The potential radiation dose to site workers and the public from management of such incidentally contaminated waste is estimated to be very low, as discussed in Section 5. Based on this analysis, DOE proposes to establish authorized limits for disposal of this soil and debris waste stream at the C-746-U landfill. Such authorized limits would supercede the current facility operating limit of 30 pCi/g total uranium, which is currently specified in the facility's waste acceptance criteria, but has not

been formally approved as an authorized limit. Authorized limits for future waste streams will be evaluated by a DOE Health Physicist on a case-by-case basis. An inventory of materials will be maintained at both the Site Office and the C-746-U Landfill Site. The total inventory of materials disposed of under the Authorized Limits will be evaluated on an annual basis.

The primary radioactive material encountered in soil and debris wastes at PGDP is uranium, including the radioisotopes Uranium-234 (^{234}U), Uranium-235 (^{235}U), and Uranium-238 (^{238}U). Wastes at the PGDP may contain uranium with various degrees of enrichment in the radioisotope ^{235}U, ranging from depleted uranium to slightly enriched uranium. For the purpose of the radiological assessment presented here, uranium isotopes are assumed to be present at their natural isotopic abundance relative to the total uranium concentration (i.e., neither enriched nor depleted in the concentration of ^{235}U relative to ^{238}U and ^{234}U). Estimates of the potential radiation dose or environmental impact from this waste stream are not highly sensitive to uncertainty in the relative distribution of uranium isotopes, since dose conversion factors for the ingestion and inhalation pathways are virtually identical for all three isotopes (EPA 1988). In addition to uranium, Technetium-99 (^{99}Tc) and trace amounts of other radionuclides have been found historically to be associated with wastes from uranium enrichment operations at PGDP. Such trace radionuclides include the transuranic radionuclides Neptunium-237 (^{237}Np), Plutonium-238 (^{238}Pu), Plutonium-239 and Plutonium-240 ($^{239/240}$Pu), and Americium-241 (^{241}Am); fission products such as Cesium-137 (^{137}Cs); and radioisotopes of thorium, primarily Thorium-230 (^{230}Th).

Proposed authorized limits for the radionuclides of concern in PGDP soil and debris are summarized in Table 1. The authorized limit for total uranium is proposed at 150 pico-Curies/gram (150 pCi/g). This proposed concentration limit is consistent with limits for disposal of Naturally Occurring Radioactive Materials (NORM) in many RCRA Subtitle D landfills. While there are no Federal regulations pertaining to disposal of NORM waste, several states have established regulatory programs for these materials. Most of these state regulations specify activity concentration limits of either 5 or 30 pCi/g (50 pCi/g in Michigan) for radium and 150 pCi/g for uranium and other natural occurring radionuclides. Kentucky has not established such regulations for natural occurring radionuclides. DOE has the authority to regulate radioactive materials that meet the requirements for disposal in an on-site landfill. This information helps provide perspective for the proposed authorized limit value. For the purpose of this analysis, the total uranium activity is assumed to be composed of approximately 49% ^{234}U (73.3 pCi/g), 2% ^{235}U (3.4 pCi/g) and 49% ^{238}U (73.3 pCi/g), consistent with the relative isotopic abundance of these isotopes in natural uranium. The results of this analysis are not highly sensitive to the isotopic distribution of uranium.

Proposed authorized limits for other radionuclides are set at 3 pCi/g for transuranic radionuclides (^{237}Np, ^{238}Pu, $^{239/240}$Pu, and ^{241}Am) and ^{137}Cs, 15 pCi/g for thorium (^{230}Th and ^{232}Th combined), and 500 pCi/g for ^{99}Tc. The proposed limits for ^{237}Np, ^{238}Pu, $^{239/240}$Pu, and ^{241}Am (3 pCi/g) are consistent with American National Standards Institute/Health Physics Society (ANSI/HPS) Standard N13.12-1999, *Surface and Volume Radioactivity Standards for Clearance* (HPS 1999). The limits proposed in this document will be for "expected or median" values. Under normal landfill operations and the Kentucky permit, some mixing of residual radioactive material at levels higher than the authorized limits with non-radioactive materials is allowed. This means verification sampling will be required prior to materials being allowed

disposal under the authorized limits. This standard specifies screening levels derived to limit the Total Effective Dose Equivalent (TEDE) from recycle, reuse, or disposal of released materials to 1 mrem/year to the public. This same value of 3 pCi/g is also proposed for ^{137}Cs, even though Standard N13.12 recommends a screening level ten-times higher (30 pCi/g) for this radionuclide. The 15 pCi/g value for thorium isotopes is based on the guidelines specified in DOE Order 5400.5, Chapter IV for thorium and radium in subsurface soils for unrestricted release. The proposed limit for ^{99}Tc is set at 500 pCi/g, based on a drinking water pathway used under a worst case exposure scenario. The ^{99}Tc value is only a fraction of the value of 3000 pCi/g specified in the ANSI Standard N13.12 for this radionuclide.

The proposed authorized limits are specified in terms of the expected or median concentration of each radionuclide of concern, including any contributions from background sources. Background concentrations of uranium in soil and rock in the Paducah area range from approximately 2 to 9 pCi/g (ORISE 1992). The DOE Risk Assessment Information System (RAIS 2000) specifies the background concentration for radionuclides in near-surface soils at the Paducah Gaseous Diffusion Plant (PGDP). The background concentration for ^{238}U is 1.2 pCi/g, 0.14 pCi/g for ^{235}U, 2.5 pCi/g for ^{234}U, 2.5 pCi/g for ^{99}Tc, 1.5 pCi/g for radioisotopes of thorium and radium, 0.49 pCi/g for ^{137}Cs, 0.1 pCi/g for ^{237}Np, 0.073 pCi/g for ^{238}Pu, and 0.025 pCi/g for ^{239}Pu. Several of these radionuclides, such as the transuranic isotopes and ^{137}Cs are not naturally occurring, but are present as background contaminants as a result of atmospheric fallout from historical nuclear weapons testing activities and other sources.

Table 1. Proposed Maximum Authorized Limits for PGDP Soil and Debris Disposal at the C-746-U Landfill

Radionuclide	Concentration * (pCi/g)	Inventory ** (Ci)
Total Uranium ***	150	2.5
Technetium-99	500	8.3
Thorium ****	15	0.3
Neptunium-237	3	0.05
Plutonium-238	3	0.05
Plutonium-239/240	3	0.05
Americium-241	3	0.05
Cesium-137	3	0.05

* Including background concentrations of each radionuclide.
** Based on a speculative initial disposal volume of 11,795 m^3 of material from the NSDD (average waste density of 1400 kg/m^3 for soil).
*** Assumes isotopic abundance of natural uranium (~49% each ^{234}U and ^{238}U, 2% ^{235}U).
**** Total value for ^{230}Th and ^{232}Th; ^{230}Th will be predominant.

Table 1 also presents the total activity inventory (Curies) of each radionuclide estimated to be disposed at the C-746-U landfill for the first year. These estimates are based on an initial disposal volume of 11,795 m^3. An annual waste disposal rate of 5000 m^3 is expected the second through seventh years. The amount of material (11,795 m^3) to be disposed of for the first year will be from the North-South Diversion Ditch remediation project. Table 2 gives the maximum, expected or median, and average detected concentrations of radionuclides found in the NSDD. The analysis presented in Section 5 evaluates the potential annual dose to site workers from management of this waste. The potential dose to workers and the public (post closure of the landfill) from the cumulative radionuclide inventory disposed at the facility is also evaluated using Residual Radiation (RESRAD) computer modeling code, with the assumption of a total of 41,795 m^3 (54,668 yd^3). This cumulative waste volume is based on a minimum mixing ratio of 1:1 of waste and clean cover materials within the landfill (Lee et al. 1995), consistent with facility operating procedures for daily cover. The estimated waste generation will occur over a period of 7 years.

Table 2. Maximum, Average, and Expected Detected Concentrations of Radionuclides Found in the NSDD

Radionuclide	Maximum Concentration * (pCi/g)	Average Concentration* (pCi/g)	Expected/Median Concentration* (pCi/g)	Expected Inventory**** (Ci)
Total Uranium **	365.6	11.3	5.3	0.1
Technetium-99	4,840.0	148.0	13.2	0.2
Thorium ***	1300.0	73.0	2.1	0.04
Neptunium-237	63.0	3.0	0.1	0.002
Plutonium-238	0.0	0.0	0.0	0.0
Plutonium-239/240	0.0	0.0	0.0	0.0
Americium-241	11.3	0.5	0.03	0.0005
Cesium-137	11.1	0.4	0.1	0.002

* Values taken from Table 2 (Appendix A, Attachment 1), and Table 1 (Appendix A, Attachment 4), *Sampling Plan for the Remedial Action for Sections 1 and 2 of the North-South Diversion Ditch to Address Near-Surface Soil Contamination at the PGDP*, October 2002.

** Assumes isotopic abundance of natural uranium (~49% each ^{234}U and ^{238}U, 2% ^{235}U).

*** Cumulative value for ^{230}Th and ^{232}Th; ^{230}Th is expected to be predominant

**** Expected inventory is from the NSDD waste stream and does not include the speculative inventory for the remaining 6 years of operation. Inventories will be tracked for each waste stream from each project, also a total inventory that includes all waste streams (see Table 1).

For the remaining 6 years, 5000 m^3 of residual radioactive material will be placed in the landfill. Each year the annual inventory of residual radioactive debris will be evaluated to maintain the public dose rate at or below 1 mrem/yr. Annual evaluations will be performed by a DOE Health Physicist to confirm that the characteristics of waste disposed at the C-746-U landfill during each year of operation are consistent with the assumptions of the analysis used to derive the proposed authorized limits. These evaluations will include comparison of the concentration of residual radioactive materials in each disposed waste stream to the authorized limit values, and calculation of the cumulative inventory of residual radioactive materials placed in the landfill to date. Supplemental analyses may be developed to request any change in the authorized limit values or duration, as necessary. In addition, different authorized limits for other waste streams may be proposed in the future on a case-by-case basis.

Wastes containerized in drums and bulk wastes are acceptable for disposal at the C-746-U landfill. Waste packaged in boxes (e.g., B-12, B-25. ST-90, 7A Type A) is not acceptable for disposal. Approximately 70% of waste disposed at the facility to date have been in bulk form, and only 30% have been containerized. A similar ratio of bulk and containerized waste is anticipated in the future.

Office trash and other non-radioactive sanitary wastes (i.e., "dumpster" waste) from non-radioactive material areas are not sent to the C-746-U landfill, but are sent to an off-site commercial, sanitary waste disposal facility. "Non-dumpster" sanitary waste also may be acceptable, when coordinated with the Landfill Manager/Operator through the processing of a "Landfill Waste Certification Package".

As noted above, wastes containing hazardous materials or characteristics regulated under RCRA Subtitle C or TSCA are prohibited from disposal at the C-746-U landfill; such wastes are sent to appropriately permitted off-site disposal facilities. In addition, wastes classified as low-level radioactive waste (i.e., wastes containing residual radioactive materials in excess of approved authorized limits) are prohibited from disposal at the C-746-U landfill, and will continue to be shipped to an approved off-site facility (e.g., Hanford, Envirocare) for disposal. Items specifically prohibited from disposal at this facility include, but are not limited to: batteries (mercury, silver, nickel-cadmium, lead-acid), bulky metal objects (desks, filing cabinets, etc.), circuit boards, classified waste, light bulbs (all types except non-hazardous "green-end" fluorescent), and waste containing free liquids.

Wastes received at the C-746-U landfill for disposal must be accompanied by appropriate documentation of compliance with waste acceptance criteria. Documentation will include a copy of a memo from the DOE Health Physicist confirming that material meets the criteria for the authorized limits, and a memo from the Bechtel Jacobs lead Health Physicist indicating that the material is either "rad" or "non-rad" added waste. All material identified as "rad-added" will then be evaluated by the DOE Health Physicist to determine if the material meets the requirements of the authorization limits.

3. C-746-U LANDFILL DESCRIPTION

The C-746-U landfill began operation in 1997 for disposal of solid wastes not regulated as hazardous materials under RCRA or TSCA regulations. The landfill is permitted by the Commonwealth of Kentucky under *Title 401 of the Kentucky Annotated Rules, Solid Waste Landfill Regulations* (401 KAR), in accordance with the requirements of Subtitle D of the Resource Conservation and Recovery Act (Solid Waste Landfill Permit #073-00045, November 4, 1996).

The PGDP includes a 750-acre fenced area within a 3400-acre federal reservation located about 10 miles west of the city of Paducah, Kentucky, and 4 miles south of the Ohio River. The C-746-U landfill is located near the northern boundary of the PGDP, approximately 2 miles southwest of the Ohio River (see Figure 1). The landfill site covers a total permitted area of approximately 59 acres, of which 22 acres is currently designated to be developed for waste disposal, with a potential disposal capacity of approximately 1,500,000 yd^3 (1,200,000 m^3)(Figure 2). Construction of the facility and emplacement of wastes is being conducted in multiple phases, proceeding from the southern end of the facility toward the northern end.

The ground surface elevation of the landfill site is approximately 360 to 370 feet above mean sea level, and about 60 feet above the average pool of the Ohio River near PGDP. Loess and continental deposits underlie alluvium soils in the PGDP area. A major hydrogeologic feature near the PGDP is the regional gravel aquifer (RGA), located in the lower continental deposits, which is the major aquifer in the area. The RGA is recharged by infiltration of precipitation through the shallow sand and upper clay layers, and ultimately discharges to the Ohio River. Average annual precipitation at Paducah, Kentucky is approximately 46 inches. Groundwater from the RGA is not currently utilized for domestic use or other purposes down gradient (north) from the PGDP. Groundwater contamination down gradient from the site was identified in 1988, and a community water line was extended to residents with contaminated wells to provide a long-term water supply.

The PGDP is located within the drainage areas of Big Bayou Creek and Little Bayou Creek, which meet about 3.5 miles north of the site and discharge into the Ohio River. Effluents from PGDP operations contribute approximately 85% of the normal flow in Big Bayou Creek and up to 100% of the normal flow in Little Bayou Creek (Kornegay et al. 1991). Both the Big Bayou Creek and Little Bayou Creek watersheds are predominantly rural in nature, with population densities on the order of 100 persons per square mile. No domestic, commercial, or industrial water withdrawals are known from either creek.

The C-746-U landfill can accept a variety of solid wastes, including soils, wood, concrete, roofing and construction debris, and other nonhazardous sanitary and industrial wastes. Waste acceptance criteria (WAC) for the facility are documented in *Waste Acceptance Criteria for the Department of Energy Treatment, Storage, and Disposal Units at the Paducah Gaseous*

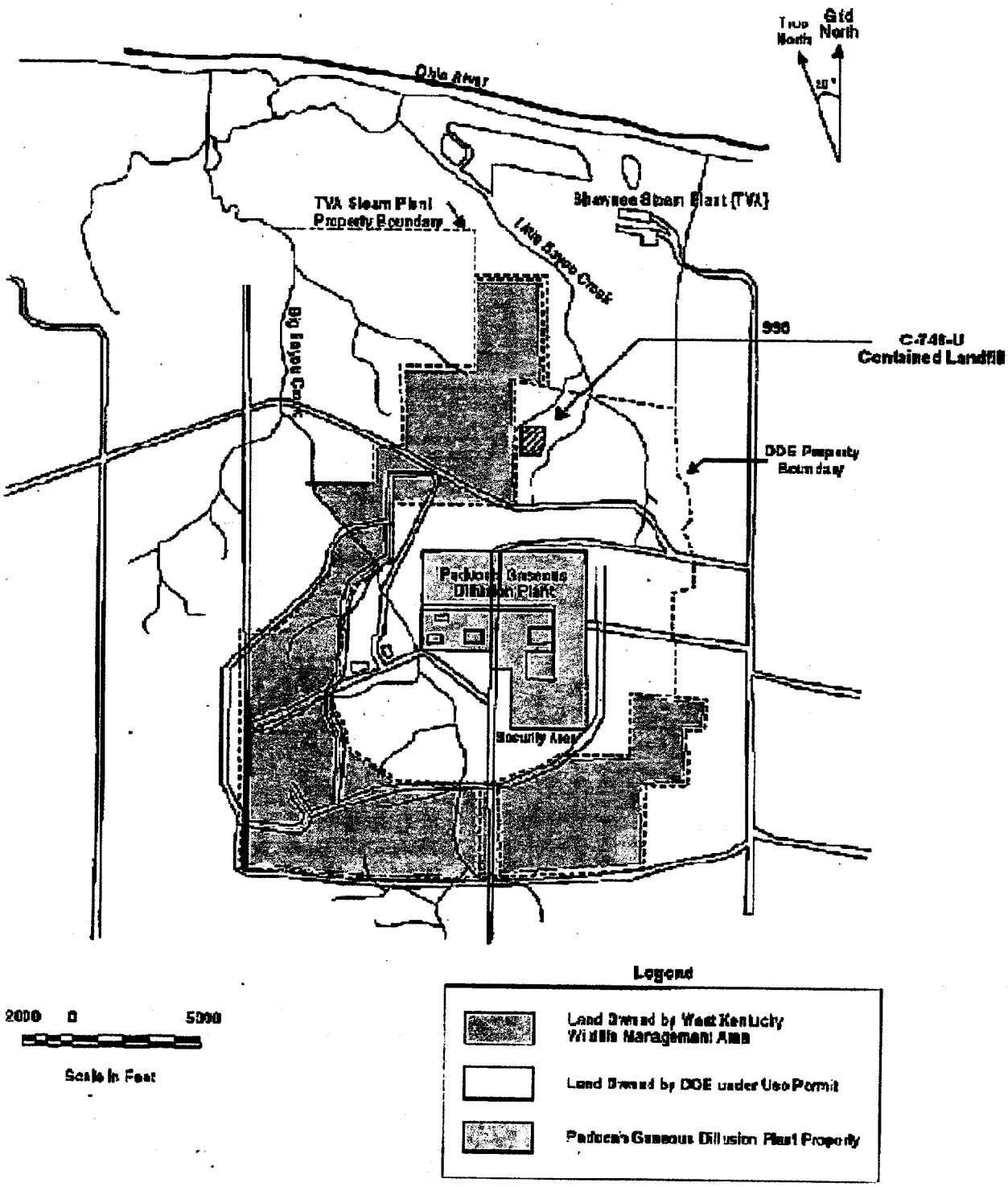

Figure 1. Location of the C-746-U Landfill at the PGDP

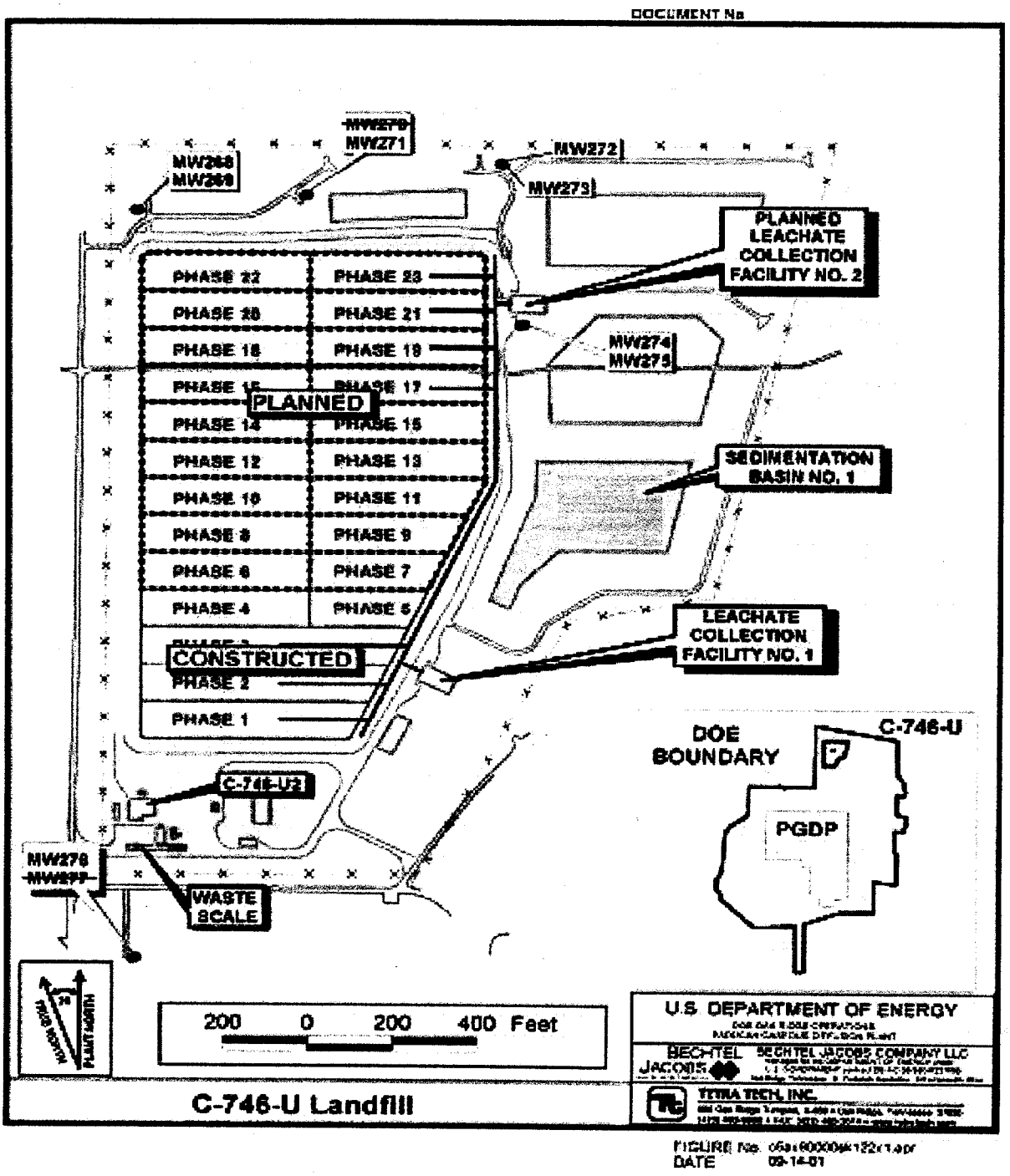

Figure 2. C-746-U Landfill

Diffusion Plant, Paducah, Kentucky (BJC 1999). The WAC includes an operating limit of 30 pCi/g for total uranium – i.e., for all waste materials. The presence of radioactive materials cannot be excluded based on process knowledge, analysis must be performed to demonstrate that total uranium concentrations do not exceed 30 pCi/g and that other potential radionuclides of concern are not present at elevated concentrations. The proposed authorized limits would supercede the current facility operational limit. Wastes with concentrations of radioactive materials above these criteria must be managed as Low Level Radioactive Waste (LLRW) in accordance with applicable regulations and DOE directives. A sample checklist used by landfill personnel to verify that appropriate documentation of compliance with waste acceptance criteria is submitted with all wastes received at the facility for disposal.

Design features of the C-746-U landfill meet all applicable technical specifications under RCRA Subpart D and 401 KAR 48, including composite liner and leachate management systems designed to prevent migration of contaminants from the unit. Approximately five acres of a contained landfill liner was constructed. The liner was constructed in accordance with the Kentucky regulations for solid waste landfills (401 KAR 48) and consisted of the following components:

1. Unstable sub-grade in Phases One and Two was remediated by over-excavating to a depth of five feet, placing woven geotextile fabric, two to three feet of limestone road base material, and two to three feet of structural backfill. Unstable sub-grade in Phases Three, Four and Five was remediated by overbuilding the design sub-grade by placing woven geotextile fabric, two feet of limestone road base material, and one foot of structural backfill. The phase-divider line between Phases Two and Three was over-excavated to provide a stable bearing surface for the road base material.

2. The sub-grade was proof rolled with a 100,000-lb loader scraper.

3. Placement of three foot thick clay with $1x10^{-7}$ cm/sec maximum hydraulic conductivity.

4. High Density Poly-Ethylene (HDPE) membrane liner (80-mils thick).

5. Use of sewn Geotextile fabric (16-oz).

6. Leachate collection and drainage layer, 12-in. non-carbonate stone with 8-in. HDPE leachate collection pipe.

7. Another layer of Geotextile fabric.

8. Gravel cushion layer made with 12-in. non-carbonate stone with a permeability greater than 0.001 cm/sec.

9. An operational soil cover with a variable thickness of 3-5 ft.

10. Hydro-seed mixture and soil stabilization fabric.

The proposed closure cap for the C-746-U landfill consists of, in ascending order, the following components:

1. Double composite geonet gas vent layer equivalent to a 12-inch sand layer with a minimum permeability of $1x10^{-3}$ cm/sec.

2. Compacted sacrificial soil layer.

3. Clay cap with a maximum permeability of $1x10^{-7}$ cm/sec and a thickness of 6 inches.

4. A 40-mils geomembrane.

5. A layer of filter fabric.

6. A minimum of 36 inches of revegetative soil.

The structural integrity of the cap is designed to exceed the minimum factor of safety specified in 401 KAR 48:080.

Facility operations are regulated by the Kentucky Department for Environmental Protection-Division of Solid Waste (for nonradiological requirements) and DOE (for radiological requirements). Closure and post-closure care requirements are designed to ensure the containment of waste materials disposed in the facility, **including long-term surveillance and monitoring.**

4. NORTH-SOUTH DIVERSION DITCH (NSDD) DESCRIPTION

The entire NSDD is located on property owned by DOE. The NSDD originates within the north-central portion of PGDP and discharges into Little Bayou Creek to the north of the plant. Little Bayou Creek originates within the West Kentucky Wildlife Management Area, south of PGDP, and flows northward to the Ohio River. Little Bayou Creek is intermittent in its upper reaches, becoming perennial down-gradient of its confluence with Out-fall 10, a continuous flow out-fall from PGDP. The southern part of the ditch is located within the plant security-fenced area, which is part of Solid Waste Management Unit 59 (SWMU 59). The northern part of the ditch is located outside the fenced area, and is part of SWMU 58.

The portion of the NSDD within the security-fenced area (SWMU 59) is approximately 793 m (2,600 ft) long (Fig. 3). This portion of the ditch varies in width from approximately 2.5 to 3.1 m (8 to 10 ft), and the depth ranges from approximately 0.2 to 1.5 m (0.5 to 5 ft). Inside the plant security fence, the ditch flows from Virginia Avenue north, beyond the C-616-C Lift Station, to the plant fence. Inside the security-fenced area, the NSDD is vegetated with grasses and is posted for radiological contamination [pursuant to *Title 10 Code of Federal Regulations (CFR) 835* requirements].

The portion of the NSDD outside the security-fenced area (SWMU 58) is approximately 2,562 m (8,400 ft) long (Fig. 4). This portion of the ditch varies in width from approximately 4.6 to 11 m (15 to 36 ft), and the depth ranges from approximately 1.5 to 4.6 m (5 to 15 ft). The banks of the NSDD outside of the security-fenced area are vegetated with grasses, brush, and trees along some sections of the ditch. Approximately 900 m (3,000 ft) of the NSDD (i.e., that portion nearest to Little Bayou Creek) fall within the 500-year floodplain of Little Bayou Creek, and some portions of this segment fall within the 100-year floodplain. The final segment of the NSDD, downstream of the C-746-U Landfill access road, is a natural, relatively unmodified stream channel. Stream flow in this channel is intermittent in the southernmost reaches, but becomes perennial as it approaches Little Bayou Creek. Upstream of the C-746-U Landfill access road, the NSDD is channeled and bordered by mown grasses, except for a short wooded segment immediately downstream of the security fence. The NSDD outside of the security-fenced area is also posted for radiological contamination (pursuant to *Title 10 CFR 835* requirements).

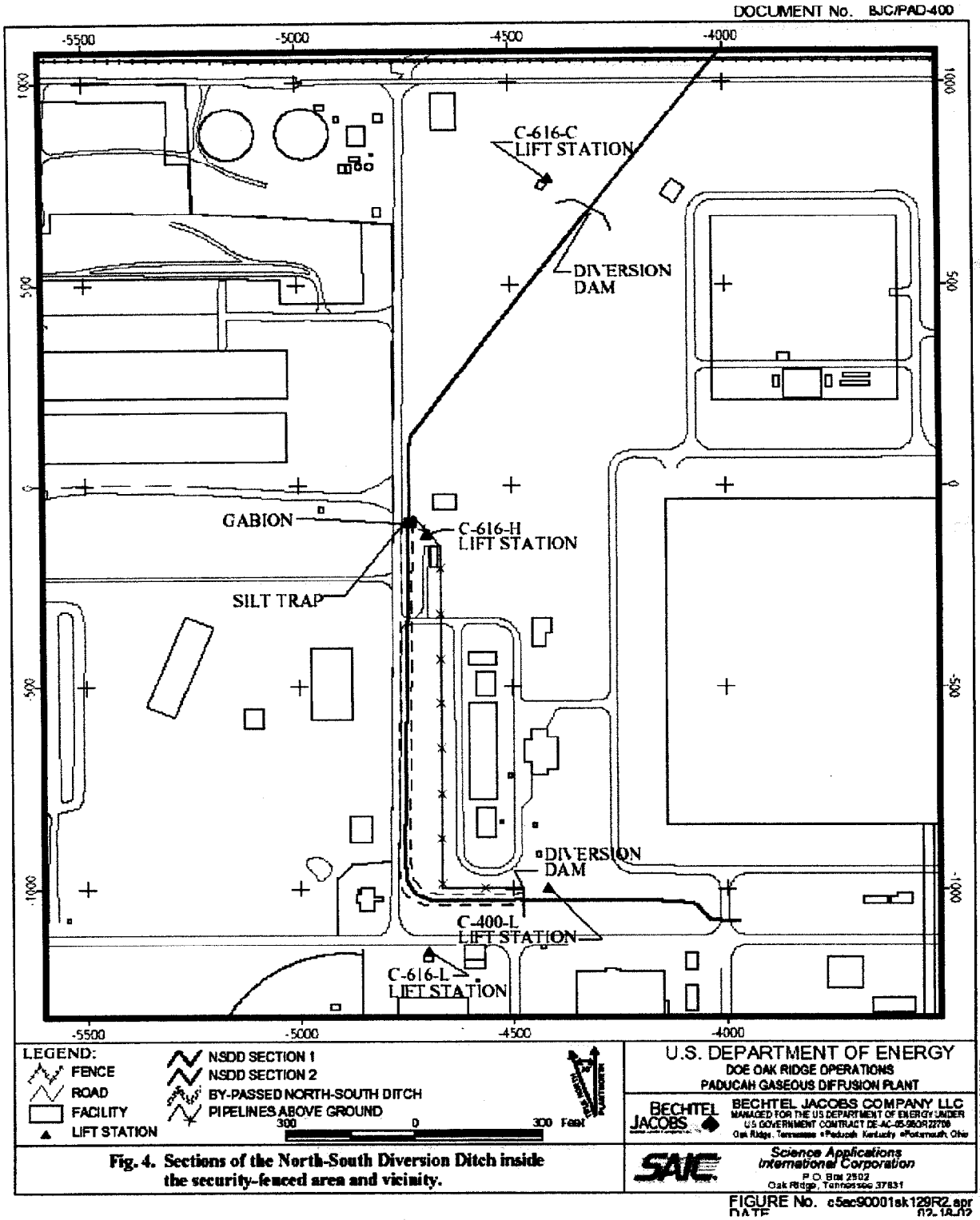

Fig. 4. Sections of the North-South Diversion Ditch inside the security-fenced area and vicinity.

Figure 3. Portion of North-South Diversion Ditch in the Security-Fenced Area

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5. RELEASE REQUIREMENTS

DOE procedures for release of real or non-real property include the determination of appropriate authorized limits and radiation survey/analysis to ensure that materials being released are below these authorized limits. For the release of materials for disposal in a DOE on-site landfill, which is not an authorized low-level waste disposal facility, the authorized limits must be (Attachment 2, DOE Standard 5506-99):

1. Selected and approved by DOE on the basis of an assessment under the ALARA process. The process will optimize the balance between risks and benefits including costs and collective doses. The process will also ensure that individual doses to the public are less than 25 mrem/year with a goal of a few mrem/year or less.

2. Evaluated to ensure that groundwater will be protected in a manner consistent with the objectives of the site's Groundwater Protection Program objectives (DOE Order 5400.1) and applicable Federal or State requirements.

3. Evaluated to verify that the release of the landfill property would not be expected to require remediation under DOE Order 5400.5 requirements for release of property containing residual radioactive material, giving due consideration to experience gained from past or ongoing CERCLA or RCRA cleanup actions.

The following sections demonstrate compliance with each of the requirements listed above. Based on the successful completion of these requirements, the proposed PGDP soil and debris waste stream is proposed for disposal at the C-746-U landfill.

5.1 Dose Assessment

Estimates of the potential radiation dose that could result from the disposal of PGDP soil and debris at the C-746-U landfill were developed by two methods:

1. The annual dose to hypothetical workers involved in the disposal of the proposed waste stream at the C-746-U landfill was estimated using the TSD-DOSE computer code (Version 2.22, Pfingston et al. 1998) which has been developed specifically for this purpose. Disposal facility workers considered to be at greatest risk of exposure to radioactive materials during the active disposal of the proposed waste stream include personnel involved in transfer of the waste from staging or generation areas at PGDP, placement of waste in the C-746-U disposal cell, and leachate collection operations.

2. Estimates of dose to hypothetical future workers at the disposal facility following closure and other potential future occupants of the site were developed using the RESRAD computer code (Version 6.21, Yu et al., 2002), based on the cumulative inventory of radioactive materials disposed at the facility.

The TSD-DOSE computer code was developed on the basis of detailed radiological assessments performed for eight commercial hazardous waste treatment, storage and disposal

(TSD) facilities. The model is designed to incorporate waste and site specific data to estimate potential radiological doses to on-site workers and the off-site public from management of waste containing very low levels of radioactive materials at a TSD facility.

On-site landfill workers will have radiological occupational training. Landfill workers will be required to complete General Employee Training (GET), Radworker II training, be enrolled in the DOE bioassay program, and take part in the DOE dosimetry program. A landfill worker meeting these requirements will be subject to Title 10, Code of Federal Regulations Part 835, *Occupational Radiation Protection.*

Input parameters for the TSD-DOSE model were adjusted to more closely approximate the site-specific circumstances at the C-746-U landfill. Input parameters for "maximum concentration" and "expected concentration" for radio-nuclides were evaluated. Potential receptors and waste processing operations considered in the TSD-DOSE code that are most applicable to the C-746-U landfill operations include:

1. Waste receiving and sampling workers - The waste receiving and sampling operation involves the activities associated with receiving the waste at the TSD facility, including weighing the vehicle; checking the manifest; and unloading, sampling and transporting the waste to a storage area. Since the waste stream considered in this analysis is generated from on-site sources at PGDP, only a portion of these activities would be potentially applicable, e.g., inspecting and weighing vehicles, and sampling of incoming waste.

2. Storage (liquid waste) - The liquid waste storage-worker scenario in the TSD-DOSE code is taken to represent the leachate collection worker, responsible for collection and disposal of any leachate generated in the landfill. This scenario is evaluated via a separate execution of the TSD-DOSE code for a liquid waste stream. The resulting estimates of dose to the leachate collection worker are highly conservative, since the entire inventory of radioactivity received annually at the landfill is assumed to reach the leachate collection tanks.

3. On-site landfill workers - The on-site landfill operation includes activities leading to burial of the waste or residues from incineration in an on-site landfill. This operation is assumed to consist of four steps; unloading waste from a dump truck to a mixing pit for stabilization, mixing the waste with stabilization agents, loading the stabilized waste into a truck and transporting it to the on-site landfill, and unloading the stabilized waste into the on-site landfill. No stabilization or treatment of the incoming soil and debris waste will be performed at the C-746-U landfill. The first operation (unloading waste into a mixing pit) is retained in order to evaluate the potential dose to landfill workers from inhalation of dust generated during waste placement in the landfill, since TSD-DOSE assumes no dust generation during placement of stabilized waste into the landfill. It is assumed that the workers will be involved in disposal of the entire volume of waste stream during each year of operation.

Potential receptors and waste processing operations considered in the TSD-DOSE code that are not applicable to the C-746-U landfill operations include the following:

1. Waste transportation - drivers involved in transporting waste from the site of generation to a distant off-site TSD facility by flatbed truck. Local transportation from the site of generation to the C-746-U landfill is addressed under the landfill worker scenario.

2. Storage before processing - workers involved in storage of contained waste prior to incineration or burial. Not applicable, because this soil and debris waste stream would be placed directly into the disposal cell on receipt without interim storage or staging. (As noted above, the liquid waste storage worker is used to represent leachate collection workers.)

3. Incineration - workers involved in incineration of the waste stream. Not applicable since no incineration of the proposed waste stream is considered.

4. Transport to an off-site landfill - workers involved in transporting incineration residues to an off-site landfill. Not applicable since no incineration of the proposed waste stream is considered.

5. Incinerator maintenance - workers involved in removal of plateout from inside the incinerator kiln. Not applicable since no incineration of the proposed waste stream is considered.

Key input parameter values assumed for these analyses are summarized in Appendix A.

Results of the TSD-DOSE analysis for disposal of soil and debris at the C-746-U landfill are summarized in Table 3, and output from TSD-DOSE is presented in Appendix A. Hypothetical maximally exposed workers involved in receipt and sampling of incoming waste and in placement of wastes in the landfill were estimated to receive potential doses of approximately 0.87 and 2.1 mrem/year, respectively. The estimated dose to the leachate collection worker is 1.1 mrem/yr. In each worker scenario, the same hypothetical individual is conservatively assumed to be involved in managing the entire inventory of waste received at the facility, and the entire waste volume is assumed to contain each radionuclide at the proposed authorized limit concentration. The potential radiation dose to a maximally exposed member of the off-site public is much lower, at 0.008 mrem/yr. Using "expected" values for the nuclides yields 0.1 mrem/year for the landfill worker, 0.045 mrem/year for the leachate collection worker, and 0.0004 mrem/year to the off-site public. These estimates are far below the primary DOE dose limit of 100 mrem/year, the limit of 25 mrem/year specified for release of materials for disposal at a DOE on-site landfill (Attachment 2, DOE Standard 5506-99) and the goal of "a few mrem/year or less."

Table 3. Estimates of Radiation Dose to Hypothetical Workers During Active Disposal Period Using the TSD-DOSE Computer Code

Exposure Pathway	Dose to Hypothetical Worker (*Maximum* Total Effective Dose Equivalent, mrem/year)			Dose to Hypothetical Worker (*Expected* Total Effective Dose Equivalent, mrem/year)		
	Waste Receiving	Waste Disposal	Leachate Collection	Waste Receiving	Waste Disposal	Leachate Collection
External	0.25	0.34	1.1	0.01	0.01	0.045
Internal	0.59	1.7	-	0.03	0.09	-
TOTAL	0.84	2.1	1.1	0.04	0.1	0.045

To the extent practicable, this assessment has been tailored to the site-specific features and operating practices of the C-746-U landfill. However, the analysis still requires many assumptions regarding the interaction of workers with waste materials, and many of these parameters have been developed through detailed time and motion studies. Key assumptions include the size and shape of the radioactive materials, distance from the worker, shielding between the source and the worker, inhalation rates, dust loading of contaminated materials in air, and any use of respiratory protection or other personal protection equipment. The parameter values and assumptions used in this analysis and incorporated in the TSD-DOSE code are designed to be conservative, i.e. likely to over-estimate potential radiation dose. In practice, standard operating procedures at this permitted landfill include placement of wastes using heavy machinery with enclosed cabs, active dust suppression measures, personnel access controls for the active disposal area, and the placement of daily cover over disposed materials to minimize the opportunity for direct contact with the waste. Therefore, actual exposures would be expected to be even lower than the estimates presented here. Additional discussion of the assumptions and parameter values used in this analysis to better represent the site-specific features and practices of the C-746-U landfill is presented in Appendix B.

The potential exposure of waste disposal workers at the facility following placement of the cumulative waste inventory in the C-746-U landfill was also evaluated using RESRAD. This evaluation assumes that the future worker is employed full-time at the landfill facility following closure for site maintenance and surveillance. The future worker was assumed to spend 8 hours/day at the disposal facility for 250 days/year, all outdoors with no shielding due to occupancy in buildings, vehicles, etc. In practice, only minimal maintenance would be required following closure of the facility, and the actual exposure frequency of the worker would be much smaller. The hypothetical worker was assumed to spend all working hours directly above the buried waste. The buried waste was assumed to be placed immediately below the final cover system (i.e., the thickness of cover materials over this waste was assumed to be only 1 meter). The maximum dose to the hypothetical future worker over the 1000-year period of analysis is

only 0.02 mrem/year, as shown in Table 4. If the actual thickness of the final cover system and any additional wastes disposed above this PGDP soil and debris waste stream exceeds 1 m, the potential dose would be even lower. In the unlikely event that a building is constructed over the disposal cell cover system, the potential concentration of radon decay products in indoor air is estimated at approximately 0.01 working level (WL), well below the applicable limit of 0.02 WL.

Since the wastes are contained in an engineered disposal cell constructed to meet the requirements of 401 KAR 48 and RCRA Subtitle D, most potential exposure pathways would be significantly restricted or eliminated. Only external radiation, radon migration through the cap and cover system, and exposure to radiation in leachate would be plausible active exposure pathways.

Table 4. Estimates of Radiation Dose to Hypothetical Receptors Following Closure of the C-746-U Landfill Using the RESRAD Computer Code

Receptor Scenario	Predicted Dose (Total Effective Dose Equivalent, mrem/year)	
	Maximum Dose	Expected Dose [a]
Worker	0.02 [b]	0.003 [b]
Resident	0.06 [b]	0.009 [b]
Farmer [d]	88.7 [c]	2.3 [c]

[a] Expected dose is based upon the more realistic (expected/median) values for radionuclides presented in Table 2.

[b] Maximum dose predicted to occur at 1000 years post-closure; primary exposure pathway is external exposure.

[c] Maximum dose to the resident farmer predicted to occur at 9 years post-closure, primarily from ingestion of ^{99}Tc in drinking water from an on-site well. Controls at the site are assumed to preclude the development of an on-site drinking water well within the 30 years of surveillance and maintenance at the landfill.

[d] A farmer residing on top of the landfill, growing crops, and raising livestock for consumption presents ultra conservative values for this evaluation. It is highly unlikely that such an event will ever occur given the administrative controls and land use controls that will be in place.

The cap and cover system would provide sufficient shielding to reduce external exposure and radon migration to negligible levels. The other potentially complete exposure pathway under normal operations would be exposure to any radioactive materials that might leach from the disposed waste and enter the leachate collection system. The leachate must be removed from the system on a weekly basis throughout the operational and closure periods for appropriate

treatment or disposal. Among the radionuclides of concern in the proposed soil and debris waste stream, only ^{99}Tc and ^{237}Np are expected to be relatively soluble and mobile. Releases of these radionuclides would be predicted to occur during the operational and active institutional control periods, while leachate is being actively collected and monitored. It should be noted that the dose estimate for the leachate collection worker discussed previously is based on the highly conservative assumptions that a hypothetical worker processes all of the leachate from the facility and that all radioactivity in the annual inventory of disposed waste reaches the leachate. The expected estimate (0.045 mrem/year) would bound any exposure from the leachate collection operations following closure of the landfill.

If the cap and cover system retains its integrity to prevent direct contact with the disposed waste and prevent placement of a groundwater well into the disposal unit, the radiation exposure to any future receptor would be negligible for any future land use. Even in the unlikely case of an intruder who might excavate into the waste, the dose would be small, particularly in light of the mixing of this small volume of waste with the overlying cover materials and surrounding waste that would occur during excavation.

Additional RESRAD calculations were performed to evaluate the highly unlikely event that institutional control is lost at some future time and the site is converted to alternative uses. The scenarios considered include; a resident located above the landfill and a subsistence farmer located above the landfill. Parameters assumed for each of these scenarios are summarized in Appendix B, along with RESRAD summary output reports.

As shown in Table 4, the potential radiation dose would remain negligibly small for worker and resident scenarios with the intact cover system, and well below 25 mrem/year. The expected dose to the hypothetical subsistence farmer is estimated to be less than 25 mrem/year. The maximum dose to the subsistence farmer is greater than 25 mrem/year, but less than the federal public dose limit of 100 mrem/year. The greater dose to the hypothetical resident farmer would be predicted if the ingestion of drinking water from an onsite well is considered to be a plausible exposure pathway. The peak dose from the drinking water pathway is estimated to occur within approximately 9 years post-closure and fall rapidly thereafter. Since the peak dose is predicted to occur within the 30-year active institutional control period following closure of the disposal cells, any contaminated leachate would be collected and appropriately disposed. The subsistence-farming scenario is not considered plausible for this site due to the requirements for permanent deed notification under the site closure requirements under 401 KAR 48. Similarly, the complete loss of the cover system would be contrary to closure and post-closure requirements for the facility and is not considered plausible, particularly in consideration of ongoing remedial actions at the PGDP site. The results for both farmer scenarios were below 100 mrem/year dose.

The collective population dose to workers at the disposal facility and off-site public within a 50-mile radius of the site was also evaluated, using the TSD-DOSE computer code. For this waste stream, the estimated maximum collective dose is 0.014 person-rem to site workers and 0.026 person-rem to the off-site public. Under both methods, the predicted radiological impacts are extremely small. Depending on the scenario, different parameters most significantly influence the results in each case. Estimates of potential doses to hypothetical future workers or

residents are predominately attributed to the external exposure pathway so that uncertainties in parameters affecting this pathway (e.g., occupancy factors, thickness and configuration of source materials, shielding provided by buildings or site features) have the greatest impact on model predictions. For these scenarios, uncertainties are relatively smaller than for the subsistence farming scenario, where uncertainties related to the leaching and transport of radionuclides from the waste materials and uptake of radionuclides by plants also influence the results. Parameter values for this analysis have been selected to provide conservative (i.e., more likely to over-estimate than to under-estimate) estimates of potential radiation dose to future receptors for all scenarios considered.

5.2 Ground Water Protection

As noted previously, groundwater contamination down gradient from the PGDP was identified in 1988, and an alternative water supply (community water line) was provided to all users with potentially impacted wells. Currently, groundwater down gradient from the PGDP is not utilized for a drinking water source or other uses.

The PGDP has developed a draft *Groundwater Protection Management Plan* developed under DOE Order 5400.1 (DOE 1997b). In addition, the *Paducah Groundwater Protection Plan* (DOE 1998) developed under Kentucky Administrative Regulation 5:037, requires that all potential source areas of groundwater contamination must be identified and addressed with respect to groundwater protection.

The C-746-U landfill has been designed to meet all technical specifications of 401 KAR 48 (and RCRA Subtitle D), including the presence of a composite liner and leachate collection system to prevent releases to groundwater. Post-closure care requirements include long-term monitoring of the leachate collection system and groundwater at the facility boundary. These design features and permit requirements will ensure that groundwater will be protected in accordance with applicable State and Federal regulations. Therefore, no detrimental impacts to groundwater from this facility are expected.

Even in the highly unlikely event that all design features and post-closure care requirements for the facility fail immediately following the 30-year active institutional control period, no significant impacts to groundwater would be predicted, due to the very low concentrations of residual radioactive materials in the proposed waste stream. Prior to the construction of the C-746-U facility, technical analyses were conducted to evaluate potential impacts to groundwater from disposal of waste containing low levels of radioactive materials (Lee et al. 1995). This analysis assumed that about one-half the total disposal capacity of the C-746-U landfill would be utilized over a 100-year period (~11 acres). This portion of the facility was considered to consist of five segments, which were to be filled sequentially beginning at the southern boundary, with each segment being filled over a 20-year active disposal period. Following the active disposal period, each unit would be closed in accordance with permit requirements, including installation of the final cover system. The cover system and leachate collection system were assumed to operate as designed for a 30-year institutional control period following closure of each unit, and then to degrade to natural conditions. No consideration was

given to the possibility that active or passive institutional controls may be maintained beyond 30 years at the disposal site. Based on these conservative assumptions, potential releases of radionuclides to groundwater were modeled, and a concentration limit for each radionuclide was computed to limit the radiation dose to a hypothetical receptor at the site boundary using groundwater as his or hers sole drinking water source not to exceed 4 mrem/yr.[1] The results of this analysis are summarized in Table 5. The derived concentration limits from this study are similar to the proposed authorized limits for uranium, and significantly greater than the proposed authorized limits for all radioisotopes of thorium, plutonium, and americium. The derived concentration limits shown in Table 5 for ^{237}Np and ^{99}Tc, however, are lower than the proposed authorized limit values for these radionuclides. It must be noted that the Lee et al. (1995) analysis considered a quantity of waste more than five times greater than the authorized limits proposed. It assumed that the entire quantity of waste contained each radionuclide at the maximum concentration limit and assumed the failure of all site engineering controls following the 30-year period of active institutional control. In consideration of the conservative assumptions built into the Lee et al. analysis, the proposed authorized limits are considered to be protective of groundwater resources for all radionuclides of concern, even for the highly unlikely case where off-site groundwater is used for a drinking water resource. Moreover, ^{237}Np and ^{99}Tc are the most mobile of all the radionuclides considered in this analysis, and would be most likely to be captured in the leachate collection system during the facility operation and closure periods.

[1] The dose constraint of 4 mrem/year was selected based on current and proposed regulations for radionuclides in drinking water under 40 CFR 141. It should be noted that this limit only applies to man-made beta-gamma emitting radionuclides, and would not be directly applicable to most of the radionuclides considered to be present in the proposed soil and debris waste stream. Among the radionuclides in Table 1, this limit would be applicable only to ^{99}Tc and ^{137}Cs, but not to the other radionuclides, which are alpha emitters. The only current limitation directly applicable to the alpha emitting radionuclides would be the gross alpha limit of 15 pCi/L. The 4 mrem/year value was used in the Lee et al (1995) study to provide a consistent basis for comparison among the radionuclides of concern. Revised regulations for radionuclides in drinking water are currently under development, which may provide alternative requirements.

Table 5. Derived Concentration Limits for Radionuclides in Wastes Disposed at the C-746-U Landfill to Limit Potential Radiation Dose to a Hypothetical Receptor at the Site Boundary to 4 mrem/year from Groundwater Ingestion (from Lee et al. 1995)

Radionuclide	Predicted Peak Concentration in Groundwater (pCi/L per pCi/g)**	Time of Peak Occurrence (year)	Derived Waste Concentration Limit (pCi/g)
Uranium-238	0.35	4,740	64
Uranium-235	0.35	4,740	64
Uranium-234	0.35	4,740	64
Technetium-99	7.9	125	560
Thorium-230	0.0009	1,600,000	11,000
Thorium-232	0.0009	1,600,000	1,300
Neptunium-237	3.8	480	0.38
Plutonium-238	0.03	53,400	170,000
Plutonium-239/240	0.03	53,400	200
Americium-241	0.004	355,000	1900
Cesium-137 *	-	-	-

* Cesium-137 was not considered in the Lee et al. 1995 analysis. However, due to its short radioactive half-life (30 years) and high distribution coefficient (K_d about 300 to 5000), it would not be predicted to impact offsite groundwater, and the derived concentration limit would be effectively infinite.

** Predicted groundwater concentration at site boundary (pCi/L) per unit activity concentration (pCi/g) in waste.

5.3 Future Remediation Requirements

Site operations since uranium enrichment production began in 1952 have resulted in releases of radioactive and chemical constituents to environmental media. Environmental remediation activities at PGDP are currently being conducted in accordance with State and Federal regulations and DOE directives under a Federal Facilities Agreement. DOE has developed a strategic plan to define remediation priorities and coordinate cleanup requirements under RCRA and the Comprehensive Environmental Restoration, Compensation and Liability Act (CERCLA). Remediation activities completed to date or currently underway include groundwater extraction and treatment, provision of alternative water supplies, installation of new

caps, and excavation of contaminated materials. The C-746-U landfill and other recent waste management facilities have been developed to provide improved management of PGDP wastes.

Since the C-746-U facility is permitted under Kentucky solid waste regulations, in accordance with RCRA Subtitle D requirements, closure and post-closure care requirements are specified to minimize the potential for future remediation at the site. The closure plan for the facility establishes requirements for future maintenance, monitoring, and control of the site. Closure requirements include a permanent deed notice to inform any future occupants of the location and operating life of the facility, the nature of the waste placed in the facility, and a caution against future disturbance of the area. These measures should help ensure that the facility will not be subject to future remediation under DOE Order 5400.5 or other applicable requirements as a result of the disposal of this waste stream.

Normal landfill operating procedures, which include clean soil for cover and operation of heavy equipment to grade disposed materials and reduce void space, would result in a minimum of one to one ratio of waste to clean soil within the landfill. The average radionuclide concentrations would be effectively reduced to at least 50% of the proposed authorized limit concentrations or less. Since the proposed authorized limit concentrations are similar to DOE criteria for unrestricted release, it is unlikely that future remediation would be required to control the residual radioactive materials in this waste stream.

As noted in the preceding discussion, site-specific remediation criteria for PGDP have not yet been developed. However, the Kentucky Radiation Health and Toxic Agents Branch (Volpe 2001) has proposed that a 1 mrem/year dose be accepted as a "walk away" dose. The expected radionuclide concentrations in wastes disposed at the C-746-U landfill are predicted to be below the "walk away" dose. Moreover, these materials would be contained within an engineered permanent disposal facility and would not be available for unrestricted contact. The disposal of the proposed waste stream at the C-746-U landfill are not expected to result in a radiation dose or risk to potential future receptors that would warrant remedial action in any case.

5.4 Cost Benefit Analysis

Disposal of the proposed PGDP soil and debris wastes as low-level radioactive waste at DOE or commercial LLW disposal facilities would cost approximately $ 1,000,000 to 3,000,000 per year. This is based on an annual waste generation rate of 5,000 m^3/year and unit rates of approximately $6 (for soil) to $16 (for debris) for disposal at Envirocare and $ 9 per ft^3 for disposal the Nevada Test Site. In addition, disposal of this waste at these off-site facilities would incur significant transportation costs. Therefore, disposal of these materials at the C-746-U landfill is estimated to provide a cost savings of at least $ 7,000,000 to $21,000,000 relative to other disposal alternatives over the 7 year period considered for this analysis.

A conservative estimate of the cost per dose averted can be derived by dividing the estimated cost savings by the collective dose predicted to result from disposal at the C-746-U landfill (0.026 person-rem per Section 5.1), or approximately $175,000,000 to $500,000,000 per person-rem averted. This approach is likely to over-estimate the dose averted (if any) by disposal

of this waste at the alternative sites. By effectively assuming zero collective dose for this disposal alternative, given the very low collective dose estimate for the landfill disposal, it is unlikely that the collective dose for any other alternative would be significantly lower. Even so, the estimate of approximately $ 1/2 billion per person-rem averted is many orders of magnitude above the levels generally considered reasonable for DOE ALARA analyses.

This cost-benefit analysis indicates that disposal of soils and debris containing low levels of radioactive materials at the C-746-U landfill would satisfy the DOE requirement to maintain all radiation exposures As Low As Reasonably Achievable (ALARA).

5.5 Reporting Requirements

Appropriate records of the released materials will be maintained consistent with the requirements of DOE Order 5400.5. Record-keeping procedures have been implemented by the C-746-U facility to meet permit requirements and DOE directives. The DOE Oak Ridge Operations Office will maintain all disposal records as part of the permanent file for the C-746-U landfill at the disposal site. As discussed in Section 2, annual evaluations will be conducted by a DOE Health Physicist to confirm that the characteristics of the wastes disposed at the landfill during each year of operation are consistent with the assumptions used in the analysis supporting the proposed authorized limits. This annual evaluation will include the development and maintenance of the cumulative source term of residual radioactive materials placed in the landfill to date, and comparison of the concentration of residual radioactive materials in each disposed waste stream to the proposed authorized limit values. Survey and measurement results will be reported consistent with the data reporting guidelines in DOE radiological survey guidance (DOE 1997c) and DOE/EH-173T (DOE 1991).

5. CONCLUSIONS

Authorized limits are proposed for the disposal of soil and debris containing low levels of residual radioactive materials at the C-746-U landfill at the DOE Paducah Gaseous Diffusion Plant (PGDP). The volume of soil and debris waste proposed for this disposal alternative is estimated at an initial disposal volume of 11,795 m^3 and an annual waste disposal rate of 5000 m^3 for the second through seventh years. This disposal alternative has been determined to meet all criteria specified in DOE guidance issued by EH-41 and EM-37 (DOE 2002) for release of wastes to a DOE-owned on-site landfill:

1. The maximum individual dose to workers at the disposal facility from the management of this waste stream is estimated at approximately 0.8 to 2.1 mrem during the active disposal operations and 0.02 mrem/year following disposal. The expected worker dose during the first year of active disposal operations is estimated at approximately 0.04 to 0.1 mrem. The maximum individual dose to the off-site public is estimated at 0.008 mrem/year, and the collective population dose (workers and public, combined) is estimated at 0.03 person-rem. The cost/benefit analysis indicates that this disposal alternative is consistent with DOE's policy to reduce radiation exposures as low as reasonably achievable (ALARA).

2. No adverse impact to groundwater is predicted. The C-746-U landfill is designed to meet technical specifications of 401 KAR 48 and RCRA Subtitle D, including a composite liner and leachate collection system. Operational and closure/post-closure care requirements for the facility include requirements for monitoring the leachate collection system and groundwater throughout the operating life of the facility and the post-closure care period. This will ensure that groundwater will be protected in accordance with applicable State and Federal regulations.

3. Disposal of this waste stream at the C-746-U landfill would not result in a future requirement for remediation of the landfill under DOE Order 5400.5. The facility has an approved closure plan for future maintenance, monitoring, and control of the site. In addition, the proposed authorized limit concentrations for this waste stream are similar to remediation criteria typically approved for unrestricted release at other DOE cleanup sites.

The disposal of the proposed PGDP soil and debris waste stream at the C-746-U landfill would provide an estimated cost savings of more than $1-3 million per year ($7-21 million over the 7-year disposal period) relative to other disposal alternatives. This disposal alternative satisfies all applicable requirements and would be consistent with DOE's policy to reduce radiation exposures as low as reasonably achievable. The analysis presented here demonstrates that the residual radioactive materials in the proposed soil and debris waste stream do not require control under the AEA and can be safely managed at the C-746-U landfill.

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APPENDIX A

TSD-DOSE ESTIMATES OF POTENTIAL RADIOLOGICAL IMPACTS FROM ACTIVE DISPOSAL OPERATIONS

The dose to hypothetical workers involved in the disposal of the proposed soil and debris waste stream at the C-746-U landfill was estimated using the TSD-DOSE computer code (Pfingston et al. 1998). TSD-DOSE was developed on the basis of detailed radiological assessments performed for eight commercial hazardous waste treatment, storage and disposal (TSD) facilities. The model is designed to incorporate waste- and site-specific data to estimate potential radiological doses to on-site workers and the off-site public from management of waste containing very low levels of radioactive materials at a TSD facility.

Default parameter values for the TSD-DOSE model were adjusted to approximate the site-specific circumstances at the C-746-U landfill. Potential receptors and waste processing operations considered in the TSD-DOSE code, and their applicability to the C-746-U landfill operations include the following:

- Waste transportation - Drivers involved in transporting waste from the site of generation to a distant off-site TSD facility by flatbed truck (40 drums per flatbed truck). Local transportation from the site of generation to the C-746-U landfill is addressed under the landfill worker scenario.

- Waste receiving and sampling workers - The waste receiving and sampling operation involves the activities associated with receiving the waste at the TSD facility, including weighing the vehicle; checking the manifest; and unloading, sampling and transporting the waste to a storage area. Since the waste stream considered in this analysis is generated from on-site sources at PGDP, only a portion of these activities would be potentially applicable, e.g., inspecting and weighing vehicles, and sampling of incoming waste.

- Storage before processing - Workers involved in storage of containerized waste prior to incineration or burial.

  - Solid waste storage - Not applicable, because soils and debris generated from other areas at PGDP would be placed directly into a disposal cell on receipt without storage.

  - Liquid waste storage - The liquid waste storage worker scenario in the TSD-DOSE code is taken to represent the leachate collection worker, responsible for collection and disposal of any leachate generated in the landfill. This scenario is evaluated via a separate execution of the TSD-DOSE code for a liquid waste stream. The resulting estimates of dose to the leachate collection worker are highly conservative, since the entire inventory of radioactivity received annually at the landfill is assumed to reach the leachate collection tanks.

- Incineration - Workers involved in incineration of the waste stream. Not applicable since no incineration of the proposed waste stream is considered.

- On-site landfill workers - The on-site landfill operation includes activities leading to burial of the waste or residues from incineration in an on-site landfill. This operation

consists of four steps; unloading waste from a dump truck, mixing the waste with stabilization agents in the mixing pit, loading the stabilized waste into a dump truck and transporting it to the on-site landfill, and unloading the stabilized waste into the on-site landfill. No stabilization or treatment of the incoming soil and debris waste is expected to be performed at the C-746-U landfill, the first operation (unloading waste into a mixing pit) is retained in order to evaluate the potential dose to landfill workers. The majority of the dose is from inhalation of dust generated during waste placement in the landfill.

- Transport to an off-site landfill - Workers involved in transporting incineration residues to an off-site landfill. Not applicable since no incineration of the proposed waste stream is considered.

- Incinerator maintenance - Workers involved in removal of plate-out from inside the incinerator kiln. Not applicable since no incineration of the proposed waste stream is considered.

In each worker scenario, the same hypothetical worker is conservatively assumed to be involved in managing the entire inventory of waste received at the facility. The entire waste volume disposed is assumed to contain each radionuclide at the proposed maximum and expected authorized limit concentration (see Table 1 and Table 2 in Section 2) for this evaluation.

On-site landfill workers will have radiological occupational training. Landfill workers will be required to complete General Employee Training (GET), Radworker II training, be enrolled in the DOE bioassay program, and take part in the DOE dosimetry program. A landfill worker meeting these requirements will be subject to Title 10, Code of Federal Regulations Part 835, *Occupational Radiation Protection.*

Default parameter values and algorithms incorporated in the TSD-DOSE code are based on many assumptions regarding the interaction of workers with waste materials, which have been developed through detailed time and motion studies. Where appropriate, these default assumptions have been revised to better represent the site-specific features and operating practices of the C-746-U landfill. Key assumptions include the size and shape of the radioactive materials, distance from the worker, shielding between the source and the worker, inhalation rate, dust loading of contaminated materials, and any use of respiratory protection or other personal protection equipment. Site-specific parameter values include the following:

Waste Receiving and Sampling Workers

TSD-DOSE assumes that all waste is containerized in standard 55-gallon drums. However, the proposed soil and debris waste stream considered here consists of approximately 70% bulk waste and 30% containerized waste, based on historical experience with remediation waste of this type. It is assumed that bulk waste will be transported to the landfill by dump truck. Each truck containing a waste volume (12.7 m^3) equivalent to approximately 61 55-gallon drums (61 x 0.208 m^3/drum). To account for this waste form, the exposure times assumed for the waste

receiving and sampling workers have been reduced - i.e., the time required for inspection and sampling of bulk waste in dump trucks is assumed to be approximately 10% of that for managing an equivalent volume of drummed waste. In addition, the respiratory protection factor for the worker involved in inspecting and sampling incoming waste was reduced from the default value of 10 to 1 (no respiratory protection), because respiratory protection is not normally used by workers at the C-746-U landfill.

On-Site Landfill Worker

TSD-DOSE considers four steps for the on-site landfill worker scenario:

(1) unloading waste from a dump truck to a mixing pit for stabilization
(2) mixing the waste with stabilization agents in the mixing pit
(3) loading the stabilized waste into a dump truck and transporting it to the on-site landfill
(4) and unloading the stabilized waste into the on-site landfill.

For analysis of the disposal of the proposed soil and debris waste stream in the C-746-U landfill, only Operations 1 and 3 were considered to apply. Operation 1 (dumping bulk waste into a stabilization pit) was used instead of operation 4 (unloading stabilized waste into a landfill) to better represent the placements of waste into the C-746-U landfill. This is necessary to evaluate the potential dose to landfill workers from inhalation of dust generated during waste placement. TSD-DOSE does not allow consideration of the inhalation pathway for the stabilized waste operation; however, no stabilization or treatment of the incoming soil and debris waste is expected to occur at the C-746-U landfill. Operation 3 (load truck and transport waste to the onsite landfill) is considered to represent the dose to workers involved in transporting waste from the staging or generation areas at PGDP to the landfill. No respiratory protection is assumed to be used by the landfill worker, based on normal site practice. Six workers are assumed to be present at the landfill during disposal operations.

The average dust loading (i.e., concentration of waste particulates of respirable size resuspended in air to which the landfill worker is exposed) during waste placement operations is assumed to be approximately 200 ug/m^3 (Yu et al. 1993b). Active dust suppression measures are implemented during waste disposal operations at the landfill, in accordance with requirements of 401 KAR 48:090-5(2). In addition, disposal operations are conducted using heavy equipment with enclosed cabs for the operator; this equipment was adopted in place of traditional open-cab equipment in order to minimize worker exposure and to alleviate safety issues associated with the use of respiratory protection equipment while operating heavy equipment.

Leachate Collection Worker

A hypothetical leachate collection worker is represented by the TSD-DOSE scenario for a liquid waste storage worker, through a separate execution of the TSD-DOSE code for a liquid waste stream with an equivalent radionuclide inventory to the proposed soil and debris waste. The resulting estimate of dose is highly conservative in that a single hypothetical worker is

assumed to conduct all leachate collection and disposal operations, and that the entire inventory of radioactivity received annually at the landfill is effectively assumed to reach the leachate collection tanks.

These input parameters and resulting estimates of potential doses are summarized in the following TSD-DOSE output reports using "expected" and "maximum" values for the radionuclides.

TSD-DOSE ESTIMATES OF POTENTIAL RADIOLOGICAL IMPACTS FROM ACTIVE DISPOSAL OPERATIONS USING EXPECTED/MEDIAN CONCENTRATION VALUES

TSD-DOSE: A Radiological Dose Assessment Model for Treatment, Storage, and Disposal Facilities

Version 2.22 - September 1998

Site: Paducah Gaseous Diffusion Plant C-746-U Landfill
Shipment: Authorized Limits for Expected Values (5.3 pCi/g U-tot; 2.1 pCi/g Th; 13.2 pCi/g Tc-99; 0.1 pCi/g Np-237
User: DOE-Paducah Site Office
Title: 11795 cubic meters first year

	TOTAL	EXTERNAL	INTERNAL
Dose to:			
Driver:	not applicable	not applicable	not applicable
Receiving worker:	4.1E-02 mrem	1.0E-02 mrem	3.1E-02 mrem
Incineration worker:	not applicable	not applicable	not applicable
Landfill worker:	1.0E-01 mrem	1.4E-02 mrem	9.1E-02 mrem
Offsite individual:	4.0E-04 mrem		
Offsite population:	1.4E-03 p-rem		
Worker Population:	7.1E-04 p-rem	1.0E-04 p-rem	6.1E-04 p-rem
Dose from:			
Transport to TSD facility:	not applicable	not applicable	not applicable
Receiving and sampling waste:	4.1E-02 mrem	1.0E-02 mrem	3.1E-02 mrem
Storage before processing:	0.0E+00 mrem	0.0E+00 mrem	not applicable
Incineration of waste:	not applicable	not applicable	not applicable
Burial at onsite landfill:	1.0E-01 mrem	1.4E-02 mrem	9.1E-02 mrem
Transport to offsite landfill:	not applicable	not applicable	not applicable
Incinerator maintenance:	not applicable	not applicable	not applicable

Doses due to each isotope (mrem - population dose in p-rem).

Isotope	Am241	Cs137+D	Np237+D	Tc99	Th230
Activity	5.0E-04 Ci	2.0E-03 Ci	2.0E-03 Ci	2.0E-01 Ci	4.0E-02 Ci
Release Fraction	5.00E-04	2.00E-03	5.00E-04	1.00E-01	5.00E-04
Driver	not applicable				
Receiving worker	2.6 E-04	4.0 E-03	2.5 E-03	1.4 E-05	1.5 E-02
Incineration worker	not applicable				
Landfill worker	7.5 E-04	5.8 E-03	5.4 E-03	1.7 E-05	4.4 E-02
Offsite individual	3.2 E-06	3.3 E-07	1.6 E-05	1.9 E-08	1.9 E-04
Offsite population	1.1 E-05	1.1 E-06	5.5 E-05	6.3 E-08	6.5 E-04
Worker population	5.0 E-06	4.3 E-05	3.7 E-05	1.3 E-07	2.9 E-04

Doses due to each isotope (cont'd).

Isotope	U234	U235+D	U238+D
Activity	5.0E-02 Ci	2.0E-03 Ci	5.0E-02 Ci
Release Fraction	5.00E-04	5.00E-04	5.00E-04
Driver	not applicable		
Receiving worker	7.5 E-03	1.2 E-03	1.1 E-02
Incineration worker	not applicable		
Landfill worker	2.2 E-02	2.0 E-03	2.5 E-02
Offsite individual	9.6 E-05	3.7 E-06	8.8 E-05
Offsite population	3.3 E-04	1.3 E-05	3.0 E-04
Worker population	1.5 E-04	1.4 E-05	1.7 E-04

Site Description

Operations included:

Receiving and sampling waste
Storage before processing
Burial at onsite landfill

Operations excluded:

Transport to TSD facility
Incineration of waste
Transport to offsite landfill
Incinerator maintenance

Parameters

The following are the adjustable parameters used to model each operation.
A (D) after a value indicates the default value was used.

Fraction solid waste = 1.000
Fraction liquid waste = 0.000
Pre-processed waste density = 7.0 E-01 g/cc
Post-processed waste density = 1.4 E+00 g/cc

Receiving and sampling waste (5 steps)
Number of Workers: 2.0E+00 (D)

Step A: Weight truck, inspect manifest
average distance: 5.00E+00 feet (D)
duration: 2.50E-01 hours

Step B: Unload drums
average distance: 3.00E+00 feet (D)
time per drum or pallet: 8.33E-03 hours

Step C: Inspect and sample drums
average distance: 3.00E+00 feet
time per drum: 8.33E-03 hours
airborne respirable dust concentration: 1.0E+00 mg/m3
respiratory protection factor: 1.0E+00

Step D: Transfer solids to storage
average distance: 3.00E+00 feet (D)
time per drum or pallet: 0.00E+00 hours

Step E: Pump drummed oil to storage tank
average distance: 5.00E-01 feet (D)
time per drum: 0.00E+00 hours

Storage before processing (3 steps)

Step A: Workers in solid waste storage area
average distance: 3.00E+00 feet (D)
duration: 0.00E+00 hours

Step B: Transfer solids out
average distance: 3.00E+00 feet (D)
time per drum or pallet: 0.00E+00 hours

Storage before processing (cont'd)

Step C: Workers in liquid waste storage area
average distance: 3.00E+00 feet (D)
duration: 0.00E+00 hours
shielding thickness: 1.25E-01 inches (D)
Storage tank dimensions:
length: 7.00E+00 feet (D)
width: 7.00E+00 feet (D)
height: 1.20E+01 feet (D)

Burial at onsite landfill (4 steps)
Number of Workers: 6.0E+00
Dump truck bed dimensions for steps A, C, and D):
length: 2.50E+01 feet (D)
width: 6.00E+00 feet (D)
height: 3.00E+00 feet (D)

Step A: Unload waste to mixing pit
average distance: 5.00E+00 feet (D)
duration: 2.50E-01 hours (D)
shielding thickness: 1.25E-01 inches (D)
airborne respirable dust concentration: 2.0E-01 mg/m3
respiratory protection factor: 1.0E+00 (D)

Step B: Mix waste in mixing pit
average distance: 1.00E+01 feet (D)
duration: 0.00E+00 hours
cover thickness: 2.00E+00 inches (D)
Mixing pit dimensions:
length: 1.00E+01 feet (D)
width: 1.00E+01 feet (D)
depth: 1.00E+01 feet (D)
cover thickness: 2.00E+00 inches (D)

Step C: Load truck and transport to landfill
average distance: 5.00E+00 feet (D)
duration: 2.50E-01 hours (D)
shielding thickness: 1.25E-01 inches (D)

Step D: Unload truck at landfill
average distance: 5.00E+00 feet (D)
duration: 0.00E+00 hours
shielding thickness: 1.25E-01 inches (D)

TSD-DOSE: A Radiological Dose Assessment Model for Treatment, Storage, and Disposal Facilities

Version 2.22 - September 1998

Site: Paducah Gaseous Diffusion Plant C-746-U Landfill
Shipment: Authorized Limits Expected Values (5.3 pCi/g U-tot; 2.1 pCi/g Th; 13.2 pCi/g Tc-99; & others)
User: DOE-Paducah Site Office
Title: Leachate Collection Worker

	TOTAL	EXTERNAL	INTERNAL
Dose to:			
Driver:	not applicable	not applicable	not applicable
Receiving worker:	4.5E-02 mrem	4.5E-02 mrem	0.0E+00 mrem
Incineration worker:	4.5E-02 mrem	4.5E-02 mrem	0.0E+00 mrem
Landfill worker:	not applicable	not applicable	not applicable
Offsite individual:	not applicable	not applicable	not applicable
Offsite population:	not applicable	not applicable	not applicable
Worker Population:	3.6E-04 p-rem	3.6E-04 p-rem	0.0E+00 p-rem
Dose from:			
Transport to TSD facility:	not applicable	not applicable	not applicable
Receiving and sampling waste:	not applicable	not applicable	not applicable
Storage before processing:	4.5E-02 mrem	4.5E-02 mrem	not applicable
Incineration of waste:	not applicable	not applicable	not applicable
Burial at onsite landfill:	not applicable	not applicable	not applicable
Transport to offsite landfill:	not applicable	not applicable	not applicable
Incinerator maintenance:	not applicable	not applicable	not applicable

Doses due to each isotope (mrem - population dose in p-rem).

Isotope	Am241	Cs137+D	Np237+D	Tc99	Th230
Activity	5.0E-04 Ci	2.0E-03 Ci	2.0E-03 Ci	2.0E-01 Ci	4.0E-02 Ci
Release Fraction	5.00E-04	2.00E-03	5.00E-04	1.00E-01	5.00E-04
Driver	not applicable				
Receiving worker	not applicable				
Incineration worker	not applicable				
Landfill worker	not applicable				
Offsite individual	not applicable				
Offsite population	not applicable				
Worker population	2.3 E-07	1.3 E-04	4.7 E-05	5.0 E-07	1.2 E-06

4/6

Doses due to each isotope (cont'd).

Isotope	U234	U238+D	U238+D
Activity	5.0E-02 Ci	2.0E-03 Ci	5.0E-02 Ci
Release Fraction	5.00E-04	5.00E-04	5.00E-04
Driver	not applicable		
Receiving worker	not applicable		
Incineration worker	not applicable		
Landfill worker	not applicable		
Offsite individual	not applicable		
Offsite population	not applicable		
Worker population	3.6 E-07	3.3 E-05	1.4 E-04

Site Description

Operations included:

Storage before processing

Operations excluded:

Transport to TSD facility
Receiving and sampling waste
Incineration of waste
Burial at onsite landfill
Transport to offsite landfill
Incinerator maintenance

Parameters

The following are the adjustable parameters used to model each operation.
A (D) after a value indicates the default value was used.

Fraction solid waste = 0.000
Fraction liquid waste = 1.000
Pre-processed waste density = 7.0 E-01 g/cc
Post-processed waste density = 1.4 E+00 g/cc

Storage before processing (3 steps)

Step A: Workers in solid waste storage area
average distance: 3.00E+00 feet (D)
duration: 0.00E+00 hours

Step B: Transfer solids out
average distance: 3.00E+00 feet (D)
time per drum or pallet: 0.00E+00 hours

Step C: Workers in liquid waste storage area
average distance: 3.00E+00 feet (D)
duration: 1.00E+00 hours
shielding thickness: 1.25E-01 inches (D)
Storage tank dimensions:
length: 7.00E+00 feet (D)
width: 7.00E+00 feet (D)
height: 1.20E+01 feet (D)

TSD-DOSE ESTIMATES OF POTENTIAL RADIOLOGICAL IMPACTS FROM ACTIVE DISPOSAL OPERATIONS USING MAXIMUM CONCENTRATION VALUES

TSD-DOSE: A Radiological Dose Assessment Model for Treatment, Storage, and Disposal Facilities

Version 2.22 - September 1998

Site: Paducah Gaseous Diffusion Plant C-746-U Landfill
Shipment: Authorized Limits for Max Values (150 pCi/g U-tot; 15 pCi/g Th; 500 pCi/g Tc-99; 3 pCi/g others)
User: DOE-Paducah Site Office
Title: 11785 cubic meters first year

	TOTAL	EXTERNAL	INTERNAL
Dose to:			
Driver:	not applicable	not applicable	not applicable
Receiving worker:	8.7E-01 mrem	2.7E-01 mrem	6.0E-01 mrem
Incineration worker:	not applicable	not applicable	not applicable
Landfill worker:	2.1E+00 mrem	3.7E-01 mrem	1.8E+00 mrem
Offsite individual:	7.8E-03 mrem		
Offsite population:	2.6E-02 p-rem		
Worker Population:	1.4E-02 p-rem	2.7E-03 p-rem	1.2E-02 p-rem
Dose from:			
Transport to TSD facility:	not applicable	not applicable	not applicable
Receiving and sampling waste:	8.7E-01 mrem	2.7E-01 mrem	6.0E-01 mrem
Storage before processing:	0.0E+00 mrem	0.0E+00 mrem	not applicable
Incineration of waste:	not applicable	not applicable	not applicable
Burial at onsite landfill:	2.1E+00 mrem	3.7E-01 mrem	1.8E+00 mrem
Transport to offsite landfill:	not applicable	not applicable	not applicable
Incinerator maintenance:	not applicable	not applicable	not applicable

Doses due to each isotope (mrem - population dose in p-rem).

Isotope	Am241	Cs137+D	Np237+D	Pu238	Pu239
Activity	5.0E-02 Ci	5.0E-02 Ci	5.0E-02 Ci	5.0E-02 Ci	5.0E-02 Ci
Release Fraction	5.00E-04	2.00E-03	5.00E-04	5.00E-04	5.00E-04
Driver	not applicable				
Receiving worker	2.8 E-02	1.0 E-01	6.3 E-02	2.2 E-02	2.5 E-02
Incineration worker	not applicable				
Landfill worker	7.5 E-02	1.5 E-01	1.3 E-01	6.6 E-02	7.2 E-02
Offsite individual	3.2 E-04	8.2 E-06	4.1 E-04	2.9 E-04	3.2 E-04
Offsite population	1.1 E-03	2.8 E-05	1.4 E-03	9.7 E-04	1.1 E-03
Worker population	5.0 E-04	1.1 E-03	9.3 E-04	4.4 E-04	4.8 E-04

Doses due to each isotope (cont'd).

Isotope	Pu240	Tc99	Th230	U234	U235+D
Activity	5.0E-02 Ci	8.3E+00 Ci	3.0E-01 Ci	1.2E+00 Ci	1.0E-01 Ci
Release Fraction	5.00E-04	1.00E-01	5.00E-04	5.00E-04	5.00E-04
Driver	not applicable				
Receiving worker	2.5 E-02	5.7 E-04	1.1 E-01	1.8 E-01	6.0 E-02
Incineration worker	not applicable				
Landfill worker	7.2 E-02	7.2 E-04	3.3 E-01	5.3 E-01	1.0 E-01
Offsite individual	3.2 E-04	7.8 E-05	1.4 E-03	2.3 E-03	1.9 E-04
Offsite population	1.1 E-03	2.6 E-04	4.9 E-03	7.8 E-03	6.3 E-04
Worker population	4.8 E-04	5.4 E-06	2.2 E-03	3.6 E-03	7.2 E-04

Doses due to each isotope (cont'd).

Isotope	U238+D
Activity	1.2E+00 Ci
Release Fraction	5.00E-04
Driver	not applicable
Receiving worker	2.5 E-01
Incineration worker	not applicable
Landfill worker	5.9 E-01
Offsite individual	2.1 E-03
Offsite population	7.1 E-03
Worker population	4.1 E-03

Site Description

Operations included:

- Receiving and sampling waste
- Storage before processing
- Burial at onsite landfill

Operations excluded:

- Transport to TSD facility
- Incineration of waste
- Transport to offsite landfill
- Incinerator maintenance

Parameters

The following are the adjustable parameters used to model each operation.
A (D) after a value indicates the default value was used.

Fraction solid waste = 1.000
Fraction liquid waste = 0.000
Pre-processed waste density = 7.0 E-01 g/cc
Post-processed waste density = 1.4 E+00 g/cc

Receiving and sampling waste (5 steps)
Number of Workers: 2.0E+00 (D)

Step A: Weight truck, inspect manifest
average distance: 5.00E+00 feet (D)
duration: 2.50E-01 hours

Step B: Unload drums
average distance: 3.00E+00 feet (D)
time per drum or pallet: 8.33E-03 hours

Step C: Inspect and sample drums
average distance: 3.00E+00 feet
time per drum: 8.33E-03 hours
airborne respirable dust concentration: 1.0E+00 mg/m3
respiratory protection factor: 1.0E+00

Step D: Transfer solids to storage
average distance: 3.00E+00 feet (D)
time per drum or pallet: 0.00E+00 hours

Step E: Pump drummed oil to storage tank
average distance: 5.00E-01 feet (D)
time per drum: 0.00E+00 hours

Storage before processing (3 steps)

Step A: Workers in solid waste storage area
average distance: 3.00E+00 feet (D)
duration: 0.00E+00 hours

Step B: Transfer solids out
average distance: 3.00E+00 feet (D)
time per drum or pallet: 0.00E+00 hours

Storage before processing (cont'd)

Step C: Workers in liquid waste storage area
average distance: 3.00E+00 feet (D)
duration: 0.00E+00 hours
shielding thickness: 1.25E-01 inches (D)
Storage tank dimensions:
length: 7.00E+00 feet (D)
width: 7.00E+00 feet (D)
height: 1.20E+01 feet (D)

Burial at onsite landfill (4 steps)
Number of Workers: 6.0E+00
Dump truck bed dimensions for steps A, C, and D):
length: 2.50E+01 feet (D)
width: 8.00E+00 feet (D)
height: 3.00E+00 feet (D)

Step A: Unload waste to mixing pit
average distance: 5.00E+00 feet (D)
duration: 2.50E-01 hours (D)
shielding thickness: 1.25E-01 inches (D)
airborne respirable dust concentration: 2.0E-01 mg/m3
respiratory protection factor: 1.0E+00 (D)

Step B: Mix waste in mixing pit
average distance: 1.00E+01 feet (D)
duration: 0.00E+00 hours
cover thickness: 2.00E+00 inches (D)
Mixing pit dimensions:
length: 1.00E+01 feet (D)
width: 1.00E+01 feet (D)
depth: 1.00E+01 feet (D)
cover thickness: 2.00E+00 inches (D)

Step C: Load truck and transport to landfill
average distance: 5.00E+00 feet (D)
duration: 2.50E-01 hours (D)
shielding thickness: 1.25E-01 inches (D)

Step D: Unload truck at landfill
average distance: 5.00E+00 feet (D)
duration: 0.00E+00 hours
shielding thickness: 1.25E-01 inches (D)

TSD-DOSE: A Radiological Dose Assessment Model for Treatment, Storage, and Disposal Facilities

Version 2.22 - September 1998

Site: Paducah Gaseous Diffusion Plant C-746-U Landfill
Shipment: Authorized Limits Max Values (150 pCi/g U-tot; 15 pCi/g Th; 500 pCi/g Tc-99; 3 pCi/g others)
User: DOE-Paducah Site Office
Title: Leachate Collection Worker

	TOTAL	EXTERNAL	INTERNAL
Dose to:			
Driver:	not applicable	not applicable	not applicable
Receiving worker:	1.1E+00 mrem	1.1E+00 mrem	0.0E+00 mrem
Incineration worker:	1.1E+00 mrem	1.1E+00 mrem	0.0E+00 mrem
Landfill worker:	not applicable	not applicable	not applicable
Offsite individual:	not applicable	not applicable	not applicable
Offsite population:	not applicable	not applicable	not applicable
Worker Population:	6.8E-03 p-rem	6.8E-03 p-rem	0.0E+00 p-rem
Dose from:			
Transport to TSD facility:	not applicable	not applicable	not applicable
Receiving and sampling waste:	not applicable	not applicable	not applicable
Storage before processing:	1.1E+00 mrem	1.1E+00 mrem	not applicable
Incineration of waste:	not applicable	not applicable	not applicable
Burial at onsite landfill:	not applicable	not applicable	not applicable
Transport to offsite landfill:	not applicable	not applicable	not applicable
Incinerator maintenance:	not applicable	not applicable	not applicable

Doses due to each isotope (mrem - population dose in p-rem).

Isotope	Am241	Cs137+D	Np237+D	Pu238	Pu239
Activity	5.0E-02 Ci	5.0E-02 Ci	5.0E-02 Ci	5.0E-02 Ci	5.0E-02 Ci
Release Fraction	5.00E-04	2.00E-03	5.00E-04	5.00E-04	5.00E-04
Driver	not applicable				
Receiving worker	not applicable				
Incineration worker	not applicable				
Landfill worker	not applicable				
Offsite individual	not applicable				
Offsite population	not applicable				
Worker population	2.3 E-05	3.3 E-03	1.2 E-03	1.8 E-08	2.6 E-07

Doses due to each isotope (cont'd).

Isotope	Pu240	Tc99	Th230	U234	U235+D
Activity	5.0E-02 Ci	8.3E+00 Ci	3.0E-01 Ci	1.2E+00 Ci	5.0E-02 Ci
Release Fraction	5.00E-04	1.00E-01	5.00E-04	5.00E-04	5.00E-04
Driver	not applicable				
Receiving worker	not applicable				
Incineration worker	not applicable				
Landfill worker	not applicable				
Offsite Individual	not applicable				
Offsite population	not applicable				
Worker population	1.6 E-06	2.1 E-05	9.3 E-06	8.6 E-06	8.2 E-04

Doses due to each isotope (cont'd).

Isotope	U238+D
Activity	1.2E+00 Ci
Release Fraction	5.00E-04
Driver	not applicable
Receiving worker	not applicable
Incineration worker	not applicable
Landfill worker	not applicable
Offsite Individual	not applicable
Offsite population	not applicable
Worker population	3.4 E-03

Site Description

Operations included:

Storage before processing

Operations excluded:

Transport to TSD facility
Receiving and sampling waste
Incineration of waste
Burial at onsite landfill
Transport to offsite landfill
Incinerator maintenance

Parameters

The following are the adjustable parameters used to model each operation.
A (D) after a value indicates the default value was used.

Fraction solid waste = 0.000
Fraction liquid waste = 1.000
Pre-processed waste density = 7.0 E-01 g/cc
Post-processed waste density = 1.4 E+00 g/cc

Storage before processing (3 steps)

Step A: Workers in solid waste storage area
average distance: 3.00E+00 feet (D)
duration: 0.00E+00 hours

Step B: Transfer solids out
average distance: 3.00E+00 feet (D)
time per drum or pallet: 0.00E+00 hours

Step C: Workers in liquid waste storage area
average distance: 3.00E+00 feet (D)
duration: 1.00E+00 hours
shielding thickness: 1.25E-01 inches (D)
Storage tank dimensions:
length: 7.00E+00 feet (D)
width: 7.00E+00 feet (D)
height: 1.20E+01 feet (D)

APPENDIX B

RESRAD ESTIMATES OF POTENTIAL RADIOLOGICAL IMPACTS

FROM CUMULATIVE RADIONUCLIDE INVENTORY

Estimates of dose to hypothetical future workers at the C-746-U disposal facility following disposal of the PGDP soil and debris waste stream were developed using the RESRAD computer code (Version 5.82, Yu et al., 1993a). It is assumed that the hypothetical future worker will be employed full-time at the landfill facility following closure for site maintenance and surveillance. In addition to the post-closure maintenance worker, other hypothetical future occupants of the site also were evaluated, including residential and subsistence farming scenarios, even though such land use scenarios for this site are highly unlikely. In each case, potential doses to the hypothetical receptors were estimated assuming that the facility cover system remains intact, in accordance with RCRA closure and post-closure requirements. The scenarios considered are summarized below and parameter values are shown in Tables B-1 and B-2.

For each scenario, the source term is assumed to include the cumulative inventory of wastes disposed at the C-746-U landfill over the 7-year period of analysis (41,795 m^3). The entire waste volume disposed is assumed to contain each radionuclide at the proposed authorized limit concentration (see Table 1 in Section 2). Each scenario was evaluated for both maximum and expected concentrations of radionuclides in contaminated materials being placed in the landfill.

Post-Closure Maintenance Worker: The future maintenance worker was assumed to spend 8 hours/day at the disposal facility, 5 days per week, for 50 weeks per year (2000 hours/year). In practice, only minimal maintenance would be required following closure of the facility, and the actual exposure frequency of the worker would be much smaller. The hypothetical worker was conservatively assumed to spend all working hours directly above the buried waste. The waste is assumed to be placed immediately below the final cover system (i.e., the thickness of cover materials over this waste was assumed to be only 1 m, the minimum total thickness of the final cover system). If the actual thickness of the final cover system and any additional wastes disposed above the PGDP soil and debris waste stream exceeds 1 m, the potential dose would be lower than the values predicted here. Complete exposure pathways for the post-closure maintenance worker include external exposure, inhalation, and incidental soil ingestion. The worker was not assumed to ingest drinking water, plant foods, fish, meat or milk from onsite sources - i.e., the presence of engineering controls designed to meet the requirements of 401 KAR 48 and RCRA Subtitle D would be effective in eliminating these potential exposure pathways.

Resident: The future resident was assumed to spend approximately 16 hours per day, 7 days per week, for 50 weeks per year (5600 hours/year), based on standard EPA exposure scenario assumptions (EPA 1997). The resident was assumed to construct a house directly over the cover system (with a minimum thickness of 1 m) of the former disposal facility, and the soil and debris containing residual radioactive materials was assumed to be immediately below the cover. Complete exposure pathways for the resident include external exposure, inhalation, and incidental soil ingestion. The resident was not assumed to ingest drinking water, plant foods, fish, meat, or milk from onsite sources. All water for drinking and all household uses were assumed to be obtained from an off-site source not affected by site conditions (e.g., the current municipal drinking water supply).

Subsistence Farmer: The hypothetical future subsistence farmer was assumed to spend approximately 18 hours per day, 7 days per week, for 52 weeks per year (6570 hours/year) at the site. The farmer was assumed to reside in a house constructed directly over the cover system (with a minimum thickness of 1 m) of the former disposal facility, and to grow farm crops and livestock at this location. As in the previous scenarios, the soil and debris containing residual radioactive materials was assumed to be immediately below the cover. Complete exposure pathways for the subsistence farmer were assumed to include external exposure, inhalation, incidental soil ingestion, and ingestion of drinking water, plant foods, fish, meat, and milk from onsite sources. All water used for drinking, household purposes, and livestock watering was assumed to come from an on-site well constructed directly into the former landfill.

So long as the cap and cover system retains its integrity, the radiation exposure to any future receptor would be negligible for any future land use. Even in the unlikely case of an intruder who might excavate into the waste, the dose would be small, particularly in light of the mixing of this small volume of waste with the overlying cover materials and surrounding waste that would occur during excavation. Lee et al. (1995) evaluated this intrusion scenario, and radionuclide concentration limits were derived to limit the radiation dose to the hypothetical future intruder to 4 mrem/year effective dose equivalent. These derived concentration limits were significantly greater than the authorized limits proposed in this report, with the exception of ^{99}Tc, where the derived limit is less than proposed authorized limit value. Earlier analysis was based on a much larger waste inventory (i.e., the entire landfill disposal capacity was assumed to be filled with waste containing radioactive material at the derived concentration limits). Analysis does not take into account the increased shielding of the disposed material by having another layer of contaminated material and clean fill being place over the initial layer of material.

Where available, site-specific parameter values (e.g., hydrogeologic and soil parameters) were selected for consistency with previous modeling studies for the C-746-U landfill (Tetra Tech 1999, 2000). Parameter values used for this analysis are summarized in Tables B-1 and B-2, followed by summary output reports from the RESRAD code.

Table B-1. Exposure Parameters Used in the RESRAD Analysis for C-746-U.

Parameter [a]	Value			
	Unit	Worker	Resident	Farmer
Area of contaminated zone [b]	m^2	20,897.5	20,897.5	20,897.5
Thickness of contaminated zone [b]	m	2	2	2
Length parallel to aquifer flow [b]	m	100	100	100
Cover depth	m	1	1	1
Cover erosion rate	m/year	0.0006	0.0006	0.006
Contaminated zone erosion rate	m/year	0.0006	0.0006	0.006
Evapotranspiration coefficient	-	0.5	0.5	0.5
Precipitation [c]	m/year	1.28	1.28	1.28
Irrigation	m/year	0	0	0
Irrigation mode	-	not used	not used	not used
Runoff coefficient	-	0.2	0.2	0.2
Watershed area for pond	m^2	not used	not used	1,000,000
Water table drop rate	m/year	not used	not used	0.001
Well pump intake depth (below water table)	m	not used	not used	17.5
Well pumping rate	m^3/yr	not used	not used	250
Model: nondispersion (ND) or mass-balance (MB)	-	not used	not used	ND
Number of unsaturated zone strata	-	not used	not used	4
Inhalation rate	m^3/yr	8400	8400	8400
Mass loading for inhalation	g/m^3	0.0001	0.0001	0.0001
Indoor occupancy time fraction	-	0.2	0.60	0.50
Outdoor occupancy time fraction	-	0.03	0.02	0.25
Shielding factor from external radiation afforded by indoor occupancy	-	0.7	0.7	0.7
Fraction of outdoor dust present indoors	-	0.4	0.4	0.4
Shape factor, external gamma	-	1	1	1
Dilution length for airborne dust inhalation	m	3	3	3
Soil ingestion rate	g/year	12.5	36.5	36.5
Fruit, vegetable, and grain consumption	kg/year	not used	not used	160
Leafy vegetable consumption	kg/year	not used	not used	14

Milk consumption from on-site livestock	L/year	not used	not used	92
Meat consumption from on-site livestock	kg/year	not used	not used	63
Fish consumption	kg/year	not used	not used	5.4
Other seafood consumption	kg/year	not used	not used	0.9
Drinking water intake	L/year	not used	not used	510
Storage time for				
Fruits, non-leafy vegetables, grain	days	not used	not used	14
Leafy vegetables	days	not used	not used	1
Milk	days	not used	not used	1
Meat	days	not used	not used	20
Fish and seafood	days	not used	not used	7
Drinking water (well or surface water)	days	not used	not used	1
Livestock fodder	days	not used	not used	45
Fraction of drinking water from on-site well	-	not used	not used	1
Fraction of aquatic food from on-site pond	-	not used	not used	0.5
Livestock fodder intake for meat	kg/d	not used	not used	68
Livestock fodder intake for milk	kg/d	not used	not used	55
Livestock water intake for meat	L/d	not used	not used	50
Livestock water intake for milk	L/d	not used	not used	160
Livestock intake of soil	kg/d	not used	not used	0.5
Mass loading for foliar deposition	g/m^3	not used	0.0001	0.0001
Depth of soil mixing layer	m	not used	0.15	0.15
Depth of roots	m	not used	0.9	0.9
Contamination fraction				
Drinking water	-	not used	not used	1
Household water	-	not used	not used	1
Livestock	-	not used	not used	1
Irrigation	-	not used	not used	1
Produce	-	not used	not used	0.5 [d]
Meat	-	not used	not used	1.0 [d]
Milk	-	not used	not used	1.0 [d]
Groundwater fractional usage (balance from surface water)				
Drinking water	-	not used	not used	1

Household water	-	not used	not used	1
Livestock water	-	not used	not used	1
Irrigation	-	not used	not used	1
Total porosity of the house or building	-	0.1	0.1	0.1
Volumetric water content of cover material	-	not used	not used	not used
Volumetric water content of the foundation	-	0.03	0.03	0.03
Diffusion coefficient for radon gas	m^2/s			
in cover material		not used	not used	not used
in foundation material		3.0×10^{-7}	3.0×10^{-7}	3.0×10^{-7}
in contaminated zone material		2.0×10^{-6}	2.0×10^{-6}	2.0×10^{-6}
Emanating power of radon gas	-	0.25	0.25	0.25
Radon vertical dimension of mixing	m	2.0	2.0	2.0
Average annual wind speed	m/s	2	2	2
Average building air exchange rate	hr^{-1}	0.5	0.5	0.5
Height of the building (room)	m	2.5	2.5	2.5
Bulk density of building foundation	g/cm^3	2.4	2.4	2.4
Thickness of building foundation	m	0.15	0.15	0.15
Building indoor area factor	-	0	0	0
Building depth below ground surface	m	-1	-1	-1

[a] Parameter values listed are generic (RESRAD default) values except where indicated differently (Yu et al. 1993a, 1993b).
[b] For purposes of this analysis, a total volume of 41,795 m^3 of waste is assumed to be disposed in the C-746-U Landfill, and assumed to be distributed over an area of 20,897.5 m^2 and depth of 2 m. The total depth of waste in the landfill is estimated at 9 m.
[c] Site-specific estimate.
[d] Calculated by RESRAD based on the area of the contaminated zone.

Table B-2. Soil and Hydrogeological Parameter Values (from Tetra Tech 1999, 2000)

Parameter	Waste/Soil Horizon *					
	Contaminated Zone (Waste)	Bottom Liner	HU1	HU2	HU3	RGA
Thickness (m)	2	1.22	3.35	1.22	3.66	10.36
Density (g/cm^3)	1.44	1.2	1.28	1.44	1.28	1.52
Total Porosity	0.43	0.42	0.45	0.43	0.45	0.34
Effective Porosity	0.33	0.06	0.2	0.33	0.2	0.28
Soil b Parameter	4.9	11.4	10.4	4.9	5.3	4.05
Hydraulic Conductivity (m/year)	1400	0.03154	0.07884	1400	227	45000
Hydraulic Gradient	-	-	-	-	-	0.0006
Distribution Coefficient, K_d, (cm^3/g)						
Uranium	35	1600	1600	35	15	35
Thorium	3200	5800	5800	3200	3200	3200
Neptunium	5	55	55	5	25	5
Plutonium	550	5100	5100	550	1200	550
Americium	1900	8400	8400	1900	9600	1900
Cesium	280	1900	1900	280	4600	280
Technetium	0.1	1	1	0.1	0.1	0.1

* Description of Waste/Soil Horizons Considered:

Contaminated Zone - Includes the PGDP soil and debris waste stream, which is assumed to occupy a total volume of 41,795 m^3 (20,897.5 m^2 x 2 m depth).
Bottom Liner - Composite liner, primarily clay, with total thickness of approximately 4 ft (see Section 3).
HU1 - Unsaturated zone stratum 1, approximately 3.35 m, silty clay.
HU2 - Unsaturated zone stratum 2, approximately 1.22 m, sand with fines.
HU3 - Unsaturated zone stratum 3, approximately 3.66 m, silt.
RGA - Regional Gravel Aquifer, the major aquifer at the PGDP, located in the lower continental deposits (approximately 10 m thick, gravel).

RESRAD ESTIMATES OF POTENTIAL RADIOLOGICAL IMPACTS FROM CUMULATIVE RADIONUCLIDE INVENTORY USING EXPECTED/MEDIAN CONCENTRATION VALUES

Contaminated Zone Dimensions		Initial Soil Concentrations, pCi/g	
Area:	20897.50 square meters	Am-241	5.000E-02
Thickness:	2.00 meters	Cs-137	1.000E-01
Cover Depth:	1.00 meters	Np-237	1.000E-01
		Tc-99	1.320E+01
		Th-230	2.100E+00
		U-234	2.597E+00
		U-235	1.060E-01
		U-238	2.597E+00

Total Dose TDOSE(t), mrem/yr
Basic Radiation Dose Limit = 2.500E+01 mrem/yr
Total Mixture Sum M(t) = Fraction of Basic Dose Limit Received at Time (t)

t (years):	0.000E+00	1.000E+00	1.000E+01	3.000E+01	1.000E+02	5.000E+02	1.000E+03
TDOSE(t):	9.744E-08	1.035E-07	1.616E-07	3.150E-07	1.245E-06	6.800E-05	3.391E-03
M(t):	3.898E-09	4.139E-09	6.466E-09	2.063E-08	4.978E-08	2.720E-06	1.356E-04

Maximum TDOSE(t): 3.391E-03 mrem/yr at t = 1.000E+03 years

WORKER DOSE

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years

Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	6.141E-12	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Cs-137	8.751E-15	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Np-237	8.650E-11	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Tc-99	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	3.382E-03	0.9975	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-234	7.007E-06	0.0021	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-235	2.940E-08	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-238	1.486E-06	0.0004	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	3.391E-03	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.141E-12	0.0000
Cs-137	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	8.751E-15	0.0000
Np-237	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	8.650E-11	0.0000
Tc-99	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.382E-03	0.9975
U-234	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.007E-06	0.0021
U-235	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.940E-08	0.0000
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.486E-06	0.0004
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.391E-03	1.0000

*Sum of all water independent and dependent pathways.

WORKER DOSE

Contaminated Zone Dimensions

Area:	20897.50 square meters
Thickness:	2.00 meters
Cover Depth:	1.00 meters

Initial Soil Concentrations, pCi/g

Am-241	3.000E-02
Cs-137	1.000E-01
Np-237	1.000E-01
Tc-99	1.320E+01
Th-230	2.100E+00
U-234	2.597E+00
U-235	1.060E+00
U-238	2.597E+00

Total Dose TDOSE(t), mrem/yr
Basic Radiation Dose Limit = 2.500E+01 mrem/yr
Total Mixture Sum M(t) = Fraction of Basic Dose Limit Received at Time (t)

t (years):	0.000E+00	1.000E+00	1.000E+01	5.000E+01	1.000E+02	5.000E+02	1.000E+03
TDOSE(t):	2.525E-07	2.681E-07	4.187E-07	1.335E-06	3.222E-06	1.760E-04	8.777E-03
M(t):	1.010E-08	1.072E-08	1.675E-08	5.342E-08	1.289E-07	7.040E-06	3.511E-04

Maximum TDOSE(t): 8.777E-03 mrem/yr at t = 1.000E+03 years

LANDFILL RESIDENT DOSE

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years

Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	1.589E-11	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Cs-137	2.265E-14	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Np-237	2.239E-10	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Tc-99	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	8.754E-03	0.9974	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-234	1.814E-05	0.0021	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-235	7.610E-07	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-238	3.845E-06	0.0004	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	8.777E-03	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.589E-11	0.0000
Cs-137	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.265E-14	0.0000
Np-237	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.239E-10	0.0000
Tc-99	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	8.754E-03	0.9974
U-234	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.814E-05	0.0021
U-235	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.610E-07	0.0001
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.845E-06	0.0004
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	8.777E-03	1.0000

*Sum of all water independent and dependent pathways.

LANDFILL RESIDENT DOSE

Contaminated Zone Dimensions

Area:	20897.50 square meters
Thickness:	2.00 meters
Cover Depth:	1.00 meters

Initial Soil Concentrations, pCi/g

Am-241	3.000E-02
Cs-137	1.000E-01
Np-237	1.000E-01
Tc-99	1.320E+01
Th-230	2.100E+00
U-234	2.597E+00
U-235	1.060E-01
U-238	2.597E+00

Total Dose TDOSE(t), mrem/yr
Basic Radiation Dose Limit = 2.500E+01 mrem/yr
Total Mixture Sum M(t) = Fraction of Basic Dose Limit Received at Time (t)

t (years):	0.000E+00	1.000E+00	1.000E+01	5.000E+01	1.000E+02	5.000E+02	1.000E+03
TDOSE(t):	3.439E-07	3.652E-07	1.054E+00	1.821E-06	4.394E-06	7.427E-01	2.127E+00
M(t):	1.376E-08	1.461E-08	4.217E-02	7.285E-08	1.758E-07	2.971E-02	8.509E-02

Maximum TDOSE(t): 2.341E+00 mrem/yr at t = 8.48 ± 0.02 years

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 8.482E+00 years

Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	5.661E-16	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Cs-137	1.073E-07	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Np-237	6.515E-10	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Tc-99	3.748E-20	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	2.104E-07	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-234	1.042E-11	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-235	4.905E-11	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-238	2.159E-07	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	5.343E-07	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

FARMER DOSE

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
At mrem/yr and Fraction of Total Dose At t = 8.482E+00 years

Water Dependent Pathways

Radio-Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.661E-16	0.0000
Cs-137	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.073E-07	0.0000
Np-237	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.515E-10	0.0000
Tc-99	2.228E+00	0.9518	4.728E-02	0.0202	0.000E+00	0.0000	0.000E+00	0.0000	1.365E-03	0.0006	6.428E-02	0.0275	2.341E+00	1.0000
Th-230	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.104E-07	0.0000
U-234	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.042E-11	0.0000
U-235	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.905E-11	0.0000
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.159E-07	0.0000
Total	2.228E+00	0.9518	4.728E-02	0.0202	0.000E+00	0.0000	0.000E+00	0.0000	1.365E-03	0.0006	6.428E-02	0.0275	2.341E+00	1.0000

*Sum of all water independent and dependent pathways.

FARMER DOSE

RESRAD ESTIMATES OF POTENTIAL RADIOLOGICAL IMPACTS FROM CUMULATIVE RADIONUCLIDE INVENTORY USING MAXIMUM CONCENTRATION VALUES

Contaminated Zone Dimensions		Initial Soil Concentrations, pCi/g	
Area:	20897.50 square meters	Am-241	3.000E+00
Thickness:	2.00 meters	Cs-137	3.000E+00
Cover Depth:	1.00 meters	Np-237	3.000E+00
		Pu-238	3.000E+00
		Pu-239	3.000E+00
		Pu-240	3.000E+00
		Tc-99	5.000E+02
		Th-230	1.500E+01
		U-234	7.330E+01
		U-235	3.400E+00
		U-238	7.330E+01

Total Dose TDOSE(t), mrem/yr
Basic Radiation Dose Limit = 2.500E+01 mrem/yr
Total Mixture Sum M(t) = Fraction of Basic Dose Limit Received at Time (t)

t (years):	0.000E+00	1.000E+00	1.000E+01	5.000E+01	1.000E+02	5.000E+02	1.000E+03
TDOSE(t):	2.765E-06	2.780E-06	3.133E-06	5.532E-06	1.091E-05	4.943E-04	2.440E-02
M(t):	1.098E-07	1.112E-07	1.253E-07	2.213E-07	4.323E-07	1.977E-05	9.760E-04

Maximum TDOSE(t): 2.440E-02 mrem/yr at t = 1.000E+03 years

WORKER DOSE

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years

Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	6.141E-10	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Cs-137	2.625E-13	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Np-237	2.595E-09	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Pu-238	2.628E-09	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Pu-239	2.586E-08	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Pu-240	3.066E-11	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Tc-99	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	2.416E-02	0.9901	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-234	1.978E-04	0.0081	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-235	9.431E-07	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-238	4.193E-05	0.0017	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	2.440E-02	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.141E-10	0.0000
Cs-137	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.625E-13	0.0000
Np-237	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.595E-09	0.0000
Pu-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.628E-09	0.0000
Pu-239	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.586E-08	0.0000
Pu-240	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.066E-11	0.0000
Tc-99	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.416E-02	0.9901
U-234	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.978E-04	0.0081
U-235	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.431E-07	0.0000
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.193E-05	0.0017
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.440E-02	1.0000

*Sum of all water independent and dependent pathways.

WORKER DOSE

Contaminated Zone Dimensions		Initial Soil Concentrations, pCi/g	
Area:	20897.50 square meters	Am-241	3.000E+00
Thickness:	2.00 meters	Cs-137	3.000E+00
Cover Depth:	1.00 meters	Np-237	3.000E+00
		Pu-238	3.000E+00
		Pu-239	3.000E+00
		Pu-240	3.000E+00
		Tc-99	5.000E+02
		Th-230	1.500E+01
		U-234	7.350E+01
		U-235	3.400E+00
		U-238	7.350E+01

Total Dose TDOSE(t), mrem/yr
Basic Radiation Dose Limit = 2.500E+01 mrem/yr
Total Mixture Sum M(t) = Fraction of Basic Dose Limit Received at Time (t)

t (years):	0.000E+00	1.000E+00	1.000E+01	5.000E+01	1.000E+02	5.000E+02	1.000E+03
TDOSE(t):	7.106E-06	7.196E-06	8.109E-06	1.432E-05	2.797E-05	1.279E-03	6.315E-02
M(t):	2.842E-07	2.879E-07	3.243E-07	5.727E-07	1.119E-06	5.117E-05	2.526E-03

Maximum TDOSE(t): 6.315E-02 mrem/yr at t = 1.000E+03 years

LANDFILL RESIDENT DOSE

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years

Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	1.589E-09	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Cs-137	6.795E-13	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Np-237	6.716E-09	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Pu-238	6.802E-09	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Pu-239	6.694E-08	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Pu-240	7.936E-11	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Tc-99	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	6.253E-02	0.9901	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-234	5.119E-04	0.0081	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-235	2.441E-06	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-238	1.085E-04	0.0017	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	6.315E-02	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.589E-09	0.0000
Cs-137	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.795E-13	0.0000
Np-237	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.716E-09	0.0000
Pu-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.802E-09	0.0000
Pu-239	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.694E-08	0.0000
Pu-240	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.936E-11	0.0000
Tc-99	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.253E-02	0.9901
U-234	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.119E-04	0.0081
U-235	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.441E-06	0.0000
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.085E-04	0.0017
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.315E-02	1.0000

*Sum of all water independent and dependent pathways.

LANDFILL RESIDENT DOSE

Contaminated Zone Dimensions

Area:	20897.50 square meters
Thickness:	2.00 meters
Cover Depth:	1.00 meters

Initial Soil Concentrations, pCi/g

Am-241	3.000E+00
Cs-137	3.000E+00
Np-237	3.000E+00
Pu-238	3.000E+00
Pu-239	3.000E+00
Pu-240	3.000E+00
Tc-99	5.000E+02
Th-230	1.500E+01
U-234	7.330E+01
U-235	3.400E+00
U-238	7.330E+01

Total Dose TDOSE(t), mrem/yr
Basic Radiation Dose Limit = 2.500E+01 mrem/yr
Total Mixture Sum M(t) = Fraction of Basic Dose Limit Received at Time (t)

t (years):	0.000E+00	1.000E+00	1.000E+01	5.000E+01	1.000E+02	5.000E+02	1.000E+03
TDOSE(t):	9.690E-06	9.814E-06	3.993E+01	1.955E-05	3.819E-05	8.813E+00	2.228E+01
M(t):	3.876E-07	3.926E-07	1.597E+00	7.819E-07	1.528E-06	3.525E-01	8.914E-01

Maximum TDOSE(t): 8.857E+01 mrem/yr at t = 8.48 ± 0.02 years

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 8.482E+00 years

Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	5.661E-14	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Cs-137	3.218E-06	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Np-237	1.954E-08	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Pu-238	1.161E-16	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Pu-239	7.581E-13	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Pu-240	5.914E-19	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Tc-99	1.420E-18	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	1.503E-06	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-234	2.941E-10	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-235	1.573E-09	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-238	6.094E-06	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Total	1.084E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

FARMER DOSE

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 8.482E+00 years

Water Dependent Pathways

Radio-Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Am-241	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.661E-14	0.0000
Cs-137	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.218E-06	0.0000
Np-237	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.954E-08	0.0000
Pu-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.161E-16	0.0000
Pu-239	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.581E-13	0.0000
Pu-240	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.914E-19	0.0000
Tc-99	8.439E+01	0.9518	1.791E+00	0.0202	0.000E+00	0.0000	0.000E+00	0.0000	5.171E-02	0.0006	2.435E+00	0.0275	8.867E+01	1.0000
Th-230	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.503E-06	0.0000
U-234	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.941E-10	0.0000
U-235	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.573E-09	0.0000
U-238	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.094E-06	0.0000
Total	8.439E+01	0.9518	1.791E+00	0.0202	0.000E+00	0.0000	0.000E+00	0.0000	5.171E-02	0.0006	2.435E+00	0.0275	8.867E+01	1.0000

*Sum of all water independent and dependent pathways.

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